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# Preliminary Environmental Assessment of the Lignite-Fired CAFB

GCA Corp, Bedford, MA GCA Technology Div

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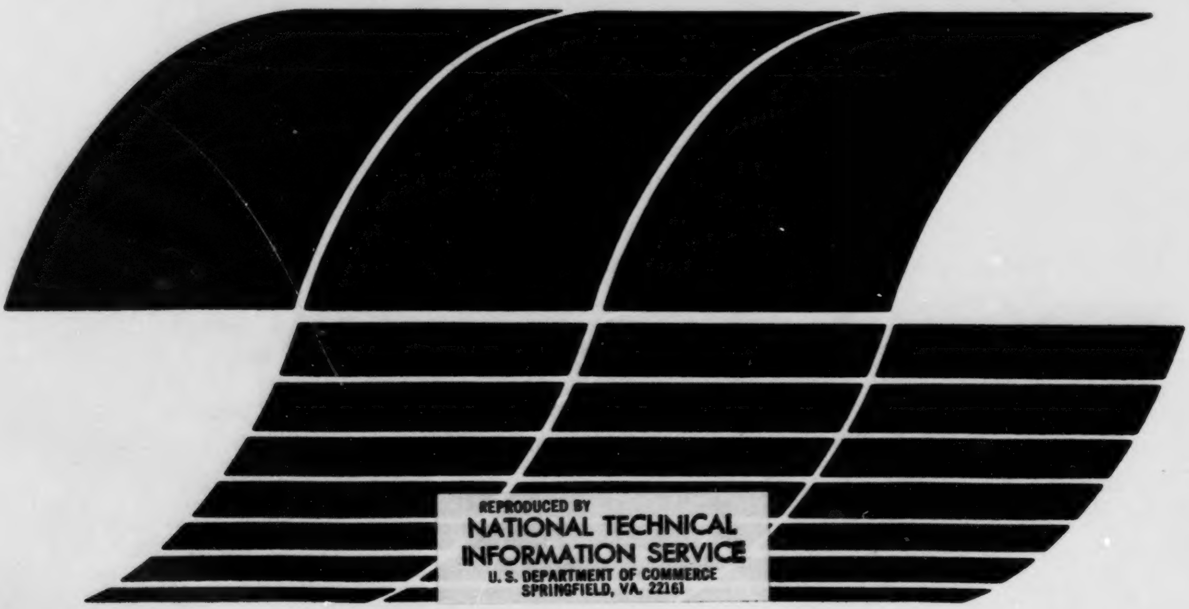

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16. ABSTRACT
The report gives results of a preliminary environmental assessment (EA) of the lignite-fired Chemically Active Fluid-Bed (CAFB) process. It follows an earlier EA of the oil-fired CAFB. Waste streams contributing air and solid waste pollutants were evaluated in terms of emission rates and potential environmental effects. Emphasis is placed on flue gas emissions. As part of the investigation, a field sampling and laboratory analysis program was carried out to compile an emissions inventory of the CAFB pilot plant at the Esso Research Centre in Abingdon, England. In addition to the EA, an economic evaluation of the oil-fired CAFB is presented relative to alternative residual oil utilization techniques. Finally, recommendations are made for further control needs and emissions testing to be carried out in conjunction with the CAFB demonstration plant in San Benito, Texas. Particulate emissions were less than those from direct combustion of lignite using multiclones as a control. NOx emissions were quite low: 0.09 lb/million Btu was the highest measured. Light organics were equal to those from conventional units; heavy (> C6) emissions were lower. SOx emissions were half the New Source Performance Standard for coal-fired boilers.

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| Assessments | Residual Oils | Stationary Sources | 14B | |
| Lignite | Coal | Environmental Assessment | 21D,08G | |
| Combustion | Sulfur Oxides | | 21B | 07B |
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by

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# ABSTRACT

This document presents the results of a preliminary environmental assessment of the lignite-fired Chemically Active Fluid Bed (CAFB) process. This report is a follow-on to an earlier environmental assessment of the oil-fired CAFB. Waste streams contributing air and solid waste pollutants were evaluated in terms of emission rates and potential environmental effects. Particular emphasis is placed on flue gas emissions. As part of this investigation, a field sampling and laboratory analysis program was carried out to compile an emissions inventory of the CAFB pilot plant at the Esso Research Centre, Abingdon (ERCA), England. In addition to the environmental assessment, an economic evaluation of the oil-fired CAFB relative to alternative residual oil utilization techniques is presented. Finally, recommendations are made for further control needs and emissions testing to be carried out in conjunction with the CAFB demonstration plant in San Benito, Texas.

Particulate emissions were less than those from direct combustion of lignite using multiclones as a control. $NO_x$ emissions were quite low with 0.09 lb/$10^6$ Btu being the highest measured. Light organics were equal to those from conventional units, while heavy ($>C_6$) organic emissions were lower. $SO_x$ emissions were one-half the NSPS for coal-fired boilers.

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# SECTION 1

# EXECUTIVE SUMMARY

## OVERVIEW

The Chemically Active Fluid Bed (CAFB) process is a technique whereby high sulfur, high metal residual oil or coal is vaporized in a fluidized bed of lime to produce a low Btu, low sulfur product gas which is then burned in a conventional boiler to generate electrical energy. Most of the sulfur and metals contained in the feed are captured by the lime. This spent lime is subsequently processed to recover sulfur.

At present, the only operating CAFB unit is a 2.93 MW pilot plant at the Esso Research Centre, Abingdon (ERCA), England facility.[1] Foster-Wheeler Energy Corporation (FW) is in the final construction stage of a 10 MW retrofit demonstration plant being installed in San Benito, Texas, at the La Palma Power Station of the Central Power and Light Company. This unit is scheduled for startup in early 1979.

The present study is an environmental assessment of the CAFB process for lignite gasification/combustion. This document is an update of GCA/Technology Division's 1976 environmental assessment of the oil-fired CAFB.[2]

The CAFB generates air, water and solid waste pollutants. The principal source of air emissions is the boiler stack which is equipped with a cyclone at both the pilot and demonstration plants. Fugitive emissions are produced by feed and waste handling and storage. At the demonstration plant these sources are contained by baghouses and, thus, will be minor contributors to total air emissions. Water effluents, such as boiler blowdown and cooling tower outputs, are similar to those produced by conventional combustion systems. Disposal of sulfided limestone with high metals content is an important environmental problem. In view of the extensive efforts[3] being conducted to develop environmentally sound methods of spent stone treatment and disposal, the program reported upon here was directed primarily toward the characterization and assessment of air emissions from the CAFB.

The data needed for the environmental assessment were acquired during an extensive sampling and analysis program of the emissions from the ERCA pilot plant. Measurement techniques included Level I of EPA's Phased Approach,[4] standard compliance methods and others selected to provide comparability of the results of this program to those of the oil-fired study.[2]

The evaluation of the results of the measurement program was accomplished by use of the Source Analysis Model SAM/IA,[5] comparison with standards of performance for coal-fired boilers and comparison with analogous results obtained by GCA for conventional lignite-fired combustion systems. Additional control requirements are noted and recommendations for additional testing at the CAFB demonstration plant are made.

In addition to the environmental analysis of the CAFB, the economic comparison between the oil-fired CAFB and alternate oil-fired energy production techniques has also been updated from the 1976 report. Eight new HDS processes are identified and described. Although the retrofit and fuel switching capability of the CAFB are not directly matched by HDS or FGD, the economic data are instructive for evaluating the marketability of the CAFB process.

## CONCLUSIONS

### Particulate Emissions

The most pressing environmental concern facing the CAFB is the need for additional control of particulate emissions. Particulate emission values determined at the ERCA pilot plant and reported here represent essentially uncontrolled emissions. The cyclone employed on the boiler stack was not designed for the CAFB and consequently cannot be assumed to have a collection efficiency of greater than 50 percent for total particulate nor greater than negligible reduction capability for particulate in the respirable size range. Emission values ranged from 2 to 4 $lb/10^6$ Btu, which represent a factor of 20 to 40 times higher than the New Source Performance Standard (NSPS) for coal-fired boilers. Ten to thirty percent of the total particulate emissions were in the respirable size range.

The CAFB particulate emission rate was about a factor of 3 lower than that measured for a conventional lignite-fired utility boiler employing multiclones for particulate control, but a factor of 2,000 higher than a boiler controlled by an ESP. To meet the current NSPS for coal-fired boilers and to comply with any potential standard for small particulate emissions, controls over and above the cyclones planned for the demonstration plant will be required.

### Trace Element Emissions

Trace element emissions can be correlated directly with particulate emissions. From a SAM/IA evaluation of these emissions, 14 elements (Ba, As, Ni, Cr, Ti, P, Si, Mg, B, Be, Cd, Sr, Cu, Li) were identified which exceeded their health MATE. For these elements, the ratios of emission rate to MATE ranged from 1 to 500. Because almost all trace elements were found in particulate samples, reduction of CAFB particulate emissions by 99.8 percent would have the concommitant effect of lowering all trace element emissions to levels below their MATE values. However, because of the uncertainty of the MATE values employed in the SAM/IA analyses and the level of precision of ±3 of the trace element emission values, such a stringent level of control may, in fact, not be required.

Trace element emissions from the conventional lignite-fired boiler are such that MATE values are exceeded by 12 elements by as much as a factor of 800. A comparison of actual emission rates with worst case values derived from lignite feed elemental composition for both the CAFB and conventional boilers supports the observation made for oil-fired CAFB operation that gasifier bed stone selectively adsorbs certain trace elements contained in the CAFB fuel.

### Gaseous Emissions

As observed in the oil-fired CAFB study, $NO_x$ emissions are significantly lower than the NSPS. The highest measured $NO_x$ emission rate for lignite-firing was 0.09 $lb/10^6$ Btu. Although this value may be low by a factor of 2 (due to possible sample degradation) the NSPS value of 0.7 $lb/10^6$ Btu is well in excess of the actual emission rate.

The measured $SO_2$ emission rate corresponds to 0.55 $lb/10^6$ Btu, roughly half the NSPS requirement. Sulfur recovery efficiency (SRE) ranged from 30 to 80 percent for the 0.5 percent sulfur lignite fired. At the lower SRE, the $SO_2$ emission rate was equal to about the NSPS value. Clearly, if the CAFB process is to be capable of using high sulfur fuel, the conditions favoring capture of fuel sulfur by bed stone must be optimized.

Emissions of $C_1$ and $C_2$ hydrocarbons (the only gaseous hydrocarbons present at levels above the detection limit) were well below their respective health-based MATE values.

### Organic Emissions

Organic emissions varied widely as a function of gasifier operating conditions. The principal conclusion which can be drawn from a comparison between CAFB emissions and those from six conventional lignite-fired boilers is that when operated efficiently, gaseous ($C_1$ - $C_6$) organic emissions from the CAFB are equivalent to those from conventional systems and emissions of heavier organics are lower than the average of those from conventional boilers.

Functional groups found in condensible CAFB air samples are esters, hydrocarbons, ketones, and amides. Other compounds provisionally identified are alcohols, phenols, amines, nitrocompounds, ethers, substituted aromatics, and organosilicon compounds. No SAM/IA analysis was performed for the organic emissions. Level II analysis of emissions from the demonstration plant will be required to generate the type of data necessary to perform a meaningful environmental assessment of organic emissions.

### Economic Comparison of Oil-Fired CAFB, FGD and HDS

The CAFB is unique as a retrofit application to natural gas-fired boilers because the process can accept a wide variety of liquid and solid fuels including those with high sulfur and high metals contents. Although flue gas desulfurization (FGD) and hydrodesulfurization (HDS) are capable of providing desulfurization equivalent to the CAFB, they are in general less capable of demetallization and reduction of $NO_x$ emissions. Consequently, any strict economic comparison of the three oil-fired systems must be qualified by considering the attendant differences in technical capabilities of CAFB, FGD and HDS.

Regenerable CAFB and FGD systems are more expensive than their once-through counterparts. Projected capital costs for the CAFB are double those of the other two processes. Estimated operating costs are also significantly higher for CAFB, as compared to flue gas desulfurization systems. In order to operate the CAFB on a competitive basis with flue gas desulfurization systems, high sulfur, high metals crudes must be $2 to $3 per barrel cheaper than low metals, medium sulfur content residual or distillate oils. At present, this per barrel differential requirement is roughly twice the market situation.

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# SECTION 2

# INTRODUCTION

## THE CHEMICALLY ACTIVE FLUID BED (CAFB) PROCESS

The Chemically Active Fluid Bed (CAFB) process was developed in the late 1960's by the Esso Research Centre, Abingdon (ERCA), England as a means to generate electrical energy from high sulfur, high metal heavy fuel oil.[1] During the early and mid 1970's, the process was demonstrated at the pilot plant stage to be capable of providing energy effectively while simultaneously limiting sulfur oxide, nitrogen oxide, vanadium and nickel air emissions to levels lower than those produced by conventional oil-firing techniques. With the realization that the supply of oil and natural gas available to the United States might soon be restricted, and that, consequently, coal would be the increasingly dominant fossil fuel source of energy in the coming decades, a decision was made to investigate the efficacy of the CAFB using coal as a retrofit for existing natural gas-fired boilers. To this end, a pilot plant test employing a Texas lignite was carried out at ERCA in early 1978.

In the CAFB process, oil or coal is fed continuously into a fluidized bed of limestone maintained at 850°C ±70°C by preheated substoichiometric air. In this gasification unit fuel is successively vaporized, oxidized, cracked and reduced. Sulfur in the fuel forms various gaseous species which in turn react with the bed stone to form calcium sulfide coated lime. Some of the fuel bound trace elements are also bound to the lime particles. The low Btu, low sulfur product gas generated in the gasifier is passed through cyclones to a conventional natural gas boiler where it undergoes combustion. The sulfided stone left in the gasifier is cycled to a regenerator unit in which it is oxidized to produce lime which is returned to the gasifier and sulfur dioxide which is sent to a sulfur recovery unit.

The ERCA pilot plant is a 2.9 MW unit. Foster-Wheeler Energy Corporation is constructing a 10 MW retrofit demonstration plant in San Benito, Texas, at the La Palma Power Station of Central Power and Light Company.[2] This unit is scheduled for startup in early 1979.

## BACKGROUND

In 1976 GCA/Technology Division prepared for EPA a report entitled "Preliminary Environmental Assessment of the CAFB."[3] The major part of that volume was devoted to an evaluation of the emission rates and potential environmental effects of the pollutants comprising all air, water and solid waste streams. This evaluation centered around a field sampling program carried out at the ERCA pilot plant during oil gasification and subsequent laboratory analysis of samples collected during testing. Because this program was performed during the period in which EPA was developing the Phased Approach to Environmental Assessments, the sampling and analytical procedures employed included both standard EPA enforcement methods and elements from the evolving Level I procedures. In addition to the experimental measurement activities, the preliminary assessment included: an engineering evaluation of potential fugitive emissions from storage and handling of feedstocks and spent material; estimates of emissions associated with cooling and boiler water; and an air quality impact assessment for the oil-fired CAFB La Palma retrofit.

The major conclusions of the environmental assessment of the oil-fired CAFB are summarized below:

- Reduction of Stack Particulate Emissions - Total stack particulate emissions from oil-fired operation of the pilot plant, 30 percent of which are in the respirable size range, were only slightly lower than the New Source Performance Standard (NSPS) for oil-fired boilers. During stone feed-startup these emissions considerably exceeded the NSPS. The vanadium concentration of these particulates is such that the vanadium emission rate is only slightly lower than the Multi-Media Environmental Goal (MEG) for this element. Under coal-fired operation of the CAFB, proposed for the demonstration plant, the particulate emission problems may be even more pronounced. Foster-Wheeler is designing more efficient cyclones than were installed at the pilot plant. Extensive particulate emission rate measurements at the demonstration plant should be undertaken for all operating modes and for all fuels.

- Reduction of $SO_2$ Emissions During Abnormal Operating Conditions - Blockage of the gasifier-regenerator transfer duct causes saturation of gasifier bed stone and a resultant increase in $SO_2$ emissions. Operation of the CAFB in this mode for extended time periods should be avoided. Continuous $SO_2$ monitoring is recommended.

- $NO_x$ Stack Emissions - Measurements of $NO_x$ emissions for three separate runs were about 25 percent of the NSPS for oil-fired boilers.

- Trace Elements Other Than Vanadium - Stack emission rates of no element other than vanadium approached creating ambient levels on the order of the MEG for that element.

- Environmentally Acceptable Disposal of Spent Stone - The demonstration plant will generate 6000 kg/day (13,000 lb/day) and a 250 MW commercial size unit 79,000 kg/day (173,000 lb/day) of sulfided, metal-contaminated lime which must be treated before being disposed of by selling, landfilling, or ocean dumping.

- Detailed Investigation of Organic Stack Emissions - Flue gas analyses indicated the possible presence of quinone, carbonyl compounds and aliphatic hydrocarbons in sufficient quantities to produce ambient concentrations in the neighborhood of the MEG's for these species. Organic emissions are highly dependent on gasifier and boiler operating conditions and should be analyzed with greater specificity than was possible in the present study.

The 1976 report included an overview of other desulfurization technologies (hydrodesulfurization (HDS) and flue gas desulfurization (FGD)) and a comparative economic evaluation of CAFB, FGD and HDS. Sixteen HDS processes were identified as actual or potential commercial systems. The unit operations of each process were identified and the attendant environmental impacts of each unit operation were discussed.

## PROGRAM OBJECTIVES

The goals of this program are to: evaluate the potential environmental impact of a lignite-fired CAFB; identify additional control needs for this process; provide recommendations for further environmental assessment of the CAFB; and update (from our 1976 report) capital and operating costs for the oil-fired CAFB and alternative oil-fired energy systems.

To collect the data necessary to the environmental assessment, an extensive sampling and analysis program of the emissions from the ERCA pilot plant was conducted. The measurement protocols closely followed Level I of EPA's Phased Approach to Environmental Assessments.[4] Additional measurements were conducted to ensure comparability of the results of this study with those of the oil-fired assessment and to provide specific data known to be required from the previous program and necessary for a clearer understanding of the CAFB process itself. Because of the extensive work on the environmental and economic implications of various solid waste disposal options being performed by other contractors,[5,6] in parallel with this study, this assessment focused primarily upon flue gas emissions from the CAFB.

The assessment of the environmental impact of the CAFB utilizes the results of the measurement program in conjunction with standards of performance for coal-fired power plants and the Source Analysis Model,[7] a scheme for ranking the relative hazards of pollutant emissions and waste streams. The output of this environmental assessment consists of the identification of control requirements for the CAFB and recommendations for follow-on assessment activities to be conducted at the demonstration plant.

In addition to the environmental analysis of the CAFB, the economic comparison between the oil-fired CAFB and alternate oil-fired energy production techniques has also been updated from the 1976 report. Eight new HDS processes are identified and described. Although the retrofit and fuel switching capability of the CAFB are not directly matched by HDS or FGD, the economic data are instructive for evaluating the marketability of the CAFB process.

# REFERENCES

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## SECTION 3

## PROCESS DESCRIPTION

### INTRODUCTION

A description of three development stages of the CAFB process, as applied to residual oil gasification, is provided in GCA's preliminary environmental assessment of the CAFB.[1] These include the 2.93 MW pilot plant constructed at the Esso Research Center, Abingdon (ERCA), England, the 22 MW demonstration plant currently in the final stages of construction at Central Power and Light's La Palma, Texas, facility (a joint effort by Foster-Wheeler Equipment Corporation and Central Power and Light), and a conceptual full scale commercial unit based on the Foster-Wheeler design. Operating parameters noted in this section are based on the results of GCA's sampling effort conducted at the ESSO pilot plant during lignite gasification, data supplied by Foster-Wheeler, and simple mass balance calculations.

### OVERVIEW

In the CAFB process, lignite is consecutively vaporized, oxidized, cracked and reduced in a fluidized bed of lime to produce a low Btu gas. This gas, from which a large portion of the sulfur has been removed by the lime, travels from the gasifier through cyclones for particulate removal and then into a conventional boiler for combustion. At the ESSO pilot plant the boiler flue gas encounters a knockout baffle and another cyclone before entering the stack. Under normal operating conditions, lime is continuously cycled between the gasifier and the regenerator where lime sulfided in the gasifier is oxidized to CaO. Sulfur dioxide produced in the regenerator is fed to the boiler stack (in the case of the pilot plant) or chemically treated to recover sulfur (for demonstration and larger designs). Spent lime is withdrawn from the regenerator for disposal on an intermittent or continuous basis. To maintain sulfur removal efficiency, an equivalent amount of limestone is added to the gasifier.

### General Description and Chemistry of Gasification

The basic components of the CAFB process are the gasifier and regenerator. Figure 1 schematically illustrates the materials fed to and withdrawn from these unit operations. The quantity of limestone added to the gasifier is determined by the Ca/S molar feed ratio necessary to provide the desired level of $SO_2$ control. Air is fed into the gasifier at about 30 percent stoichiometric in order to partially oxidize the fuel oil and produce a temperature 871°C (1600°F) suitable for vaporization and cracking of the fuel. Flue gas from the boiler at approximately 171°C (340°F) is recirculated to the gasifier for temperature control. A low Btu product gas is circulated from the gasifier to the boiler. The predominant reactions taking place in the gasifier are as follows:

$$\text{Fuel thermal cracking} \rightarrow C + H_2 + \text{hydrocarbons} + H_2S + CS_2 + COS$$

$$CaO + H_2S \rightleftharpoons CaS + H_2O$$

$$CaO + COS \rightleftharpoons CaS + CO_2$$

$$CaO + 1/2CS_2 \rightleftharpoons CaS + 1/2CO_2$$

The equilibria for these reactions are well to the right. Approximately 5 percent of the input limestone as calcium oxide is reduced to calcium sulfide on each pass of stone through the gasifier.

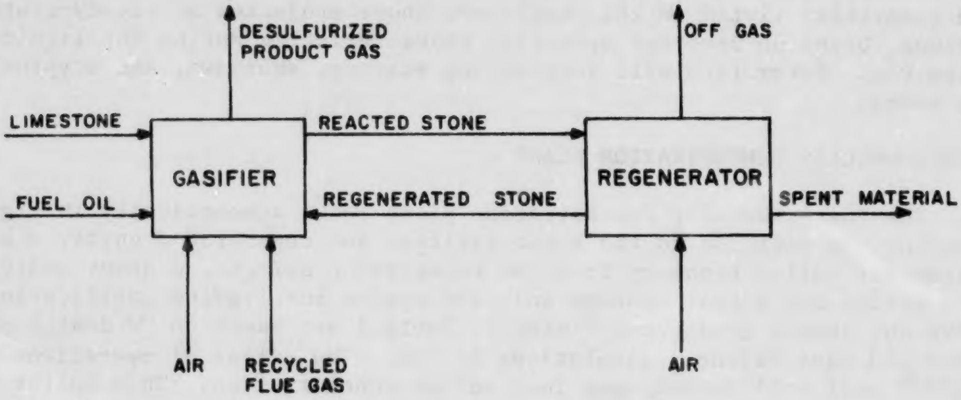
DESULFURIZED PRODUCT GAS
OFF GAS
LIMESTONE
REACTED STONE
GASIFIER
REGENERATOR
FUEL OIL
REGENERATED STONE
SPENT MATERIAL
AIR
RECYCLED FLUE GAS
AIR

Figure 1. Gasifier-regenerator schematic.

General Description and Chemistry of Regeneration

The regeneration step is accomplished in a reaction vessel adjacent to the gasifier. Bed material comprised of CaO, CaS, carbon and ash is fed to the regenerator where it reacts with a stoichiometric quantity of air by the reactions:

$$CaS + 3/2\ O_2 \rightleftharpoons CaO + SO_2$$

$$CaS + 2O_2 \rightleftharpoons CaSO_4$$

$$CaS + 3CaSO_4 \rightleftharpoons 4CaO + 4SO_2$$

Carbon deposited on the stone during gasification is oxidized to $CO_2$. Regenerator solids analyzed by ESSO during the GCA sampling run ranged between 0.1 to 2.8 percent carbon.

The off-gas from the regenerator contains $SO_2$, $CO_2$ and $N_2$ derived from the influent air. Spent solid material consists of CaO, $CaSO_4$, CaS and ash. In the Foster-Wheeler demonstration plant and 250 MW unit, off-gas will be transported to the RESOX$^{TM}$ system for recovery of elemental sulfur, and spent solids will be conveyed to a solids cooler and storage bin. At the ESSO pilot plant regenerator off-gas passes through a cyclone and then into the boiler stack.

## ESSO PILOT PLANT

Figure 2 is a schematic diagram of the ESSO pilot plant. Some physical modifications have been made since our first investigation to allow for solid fuel gasification. Input and output streams to and from each unit operation are labelled and their mass flow and characteristics are given in Table 1. The quantities listed in this table are those projected at steady-state conditions, based on recorded operating characteristics during the lignite sampling run. Parameters will vary during startup, shutdown, and atypical operating modes.

## FOSTER-WHEELER DEMONSTRATION PLANT

The Foster-Wheeler demonstration plant shown schematically in Figure 3 contains, in addition to the basic gasifier and regenerator units, a RESOX$^{TM}$ system for sulfur recovery from the regenerator off-gas, a spent solids handling system and a coal storage and feed system for lignite gasification. Mass flows and stream conditions listed in Table 2 are based on FW design parameters and mass balance calculations by GCA. The extent of operations of the RESOX$^{TM}$ unit will depend upon fuel sulfur concentration. This sulfur recovery system is designed for maximal performance with 7 to 8 percent $SO_2$ input; thus, for CAFB gasification of low sulfur fuel the RESOX$^{TM}$ may be operated intermittently to allow for $SO_2$ buildup in the regenerator.

In GCA's oil-fired assessment report, auxiliary handling and storage unit operations were discussed in depth for both oil and coal-firing. Because these operations do not appear to present appreciable environmental problems and because they are similar to facilities used in conventional boilers, we have not updated the earlier treatment.

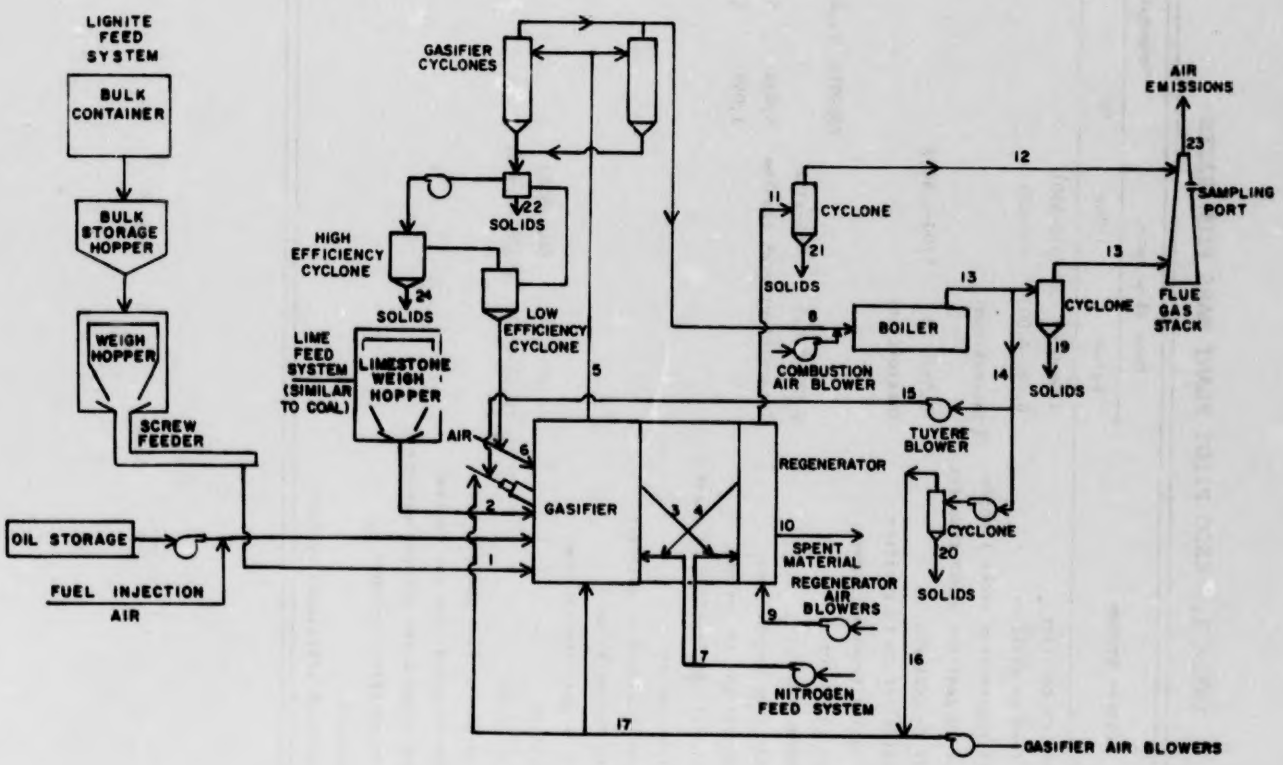
LIGNITE FEED SYSTEM
BULK CONTAINER
BULK STORAGE HOPPER
WEIGH HOPPER
SCREW FEEDER
OIL STORAGE
FUEL INJECTION AIR
GASIFIER CYCLONES
22
SOLIDS
HIGH EFFICIENCY CYCLONE
24
SOLIDS
LOW EFFICIENCY CYCLONE
LIME FEED SYSTEM (SIMILAR TO COAL)
LIMESTONE WEIGH HOPPER
AIR
6
2
1
5
GASIFIER
3
4
REGENERATOR
10
SPENT MATERIAL
7
NITROGEN FEED SYSTEM
9
REGENERATOR AIR BLOWERS
17
GASIFIER AIR BLOWERS
11
CYCLONE
21
SOLIDS
12
8
BOILER
COMBUSTION AIR BLOWER
13
CYCLONE
19
SOLIDS
14
15
TUYERE BLOWER
CYCLONE
20
SOLIDS
16
13
FLUE GAS STACK
SAMPLING PORT
23
AIR EMISSIONS

Figure 2. Unit operations flow diagram of the ESSO pilot plant.

## TABLE 1. ESSO PILOT PLANT MASS FLOW RATES

| Process stream | Mass flow rate | | Temperature | |
|---|---|---|---|---|
| | kg/sec | lb/hr | °C | °F |
| 1. Lignite feed to gasifier | 0.04-0.07 | (350-550) | | |
| 2. Limestone feed to gasifier | 0.001-0.003 | (10-20) | | |
| 3. Gasifier to regenerator stone transfer | Intermittent | | | |
| 4. Regenerator to gasifier stone transfer | | | | |
| 5. Product gas to cyclones | 0.09-0.18 | (700-1,400) | | |
| 6. Cyclone solids return to gasifier | Intermittent | | | |
| 7. $N_2$ gas to solids transfer lines | | | | |
| 8. Product gas to boiler | | | 792-913 | (1,458-1,675) |
| 9. Air to regenerator | 0.006-0.015 | (45-115) | | |
| 10. Spent solids from regenerator | Intermittent grab samples | | 1,055 | (1,931) |
| 11. Regenerator off-gas to cyclone | | | 1,055 | (1,931) |
| 12. Regenerator off-gas, cyclone to stack | | | | |
| 13. Flue gas from boiler | | | | |
| 14. Flue gas recirculated to gasifier | | | | |
| 15. Flue gas to Tuyere Blower | | | | |
| 16. Recycled flue gas from cyclone | | | | |
| 17. Air to gasifier | 0.05-0.10 | (400-800) | | |
| 18. Flue gas to stack | 0.66-0.71 | (5,200-5,600) | | |
| 19. Solids from boiler flue gas cyclone | | | | |
| 20. Solids from recycled flue gas cyclone | | | | |
| 21. Solids from regenerator off-gas cyclone | | | | |
| 22. Solids from gasifier cyclones | | | | |
| 23. Stack emissions | | | | |
| 24. Solids from high efficiency cyclone | | | | |

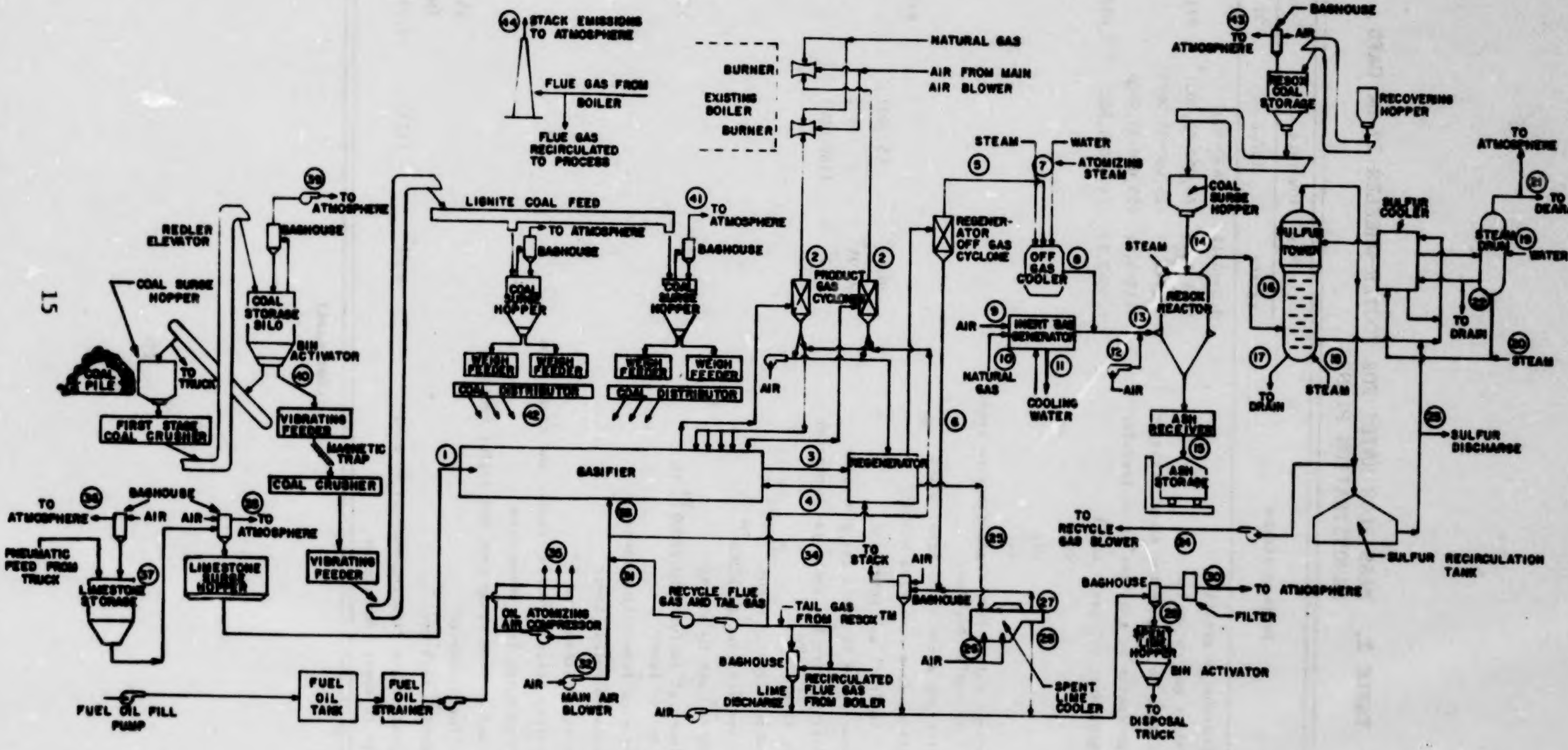
STACK EMISSIONS TO ATMOSPHERE
44
FLUE GAS FROM BOILER
FLUE GAS RECIRCULATED TO PROCESS
BURNER
EXISTING BOILER
BURNER
NATURAL GAS
AIR FROM MAIN AIR BLOWER
43
TO ATMOSPHERE
BAGHOUSE
AIR
REDOX COAL STORAGE
RECOVERING HOPPER
TO ATMOSPHERE
21
TO DEARATOR
STEAM
WATER
5
7
ATOMIZING STEAM
39
TO ATMOSPHERE
REDLER ELEVATOR
BAGHOUSE
COAL SURGE HOPPER
COAL PILE
TO TRUCK
COAL STORAGE SILO
BIN ACTIVATOR
40
FIRST STAGE COAL CRUSHER
VIBRATING FEEDER
MAGNETIC TRAP
COAL CRUSHER
VIBRATING FEEDER
LIGNITE COAL FEED
TO ATMOSPHERE
BAGHOUSE
41
TO ATMOSPHERE
BAGHOUSE
COAL SURGE HOPPER
COAL SURGE HOPPER
WEIGH FEEDER
WEIGH FEEDER
WEIGH FEEDER
WEIGH FEEDER
COAL DISTRIBUTOR
COAL DISTRIBUTOR
42
2
2
PRODUCT GAS CYCLONES
AIR
REGENERATOR OFF GAS CYCLONE
OFF GAS COOLER
8
AIR
9
INERT GAS GENERATOR
10
NATURAL GAS
11
COOLING WATER
12
AIR
13
6
COAL SURGE HOPPER
STEAM
14
REDOX REACTOR
ASH RECEIVER
15
ASH STORAGE
SULFUR TOWER
16
17
TO DRAIN
18
STEAM
SULFUR COOLER
STEAM DRUM
19
WATER
22
TO DRAIN
20
STEAM
23
SULFUR DISCHARGE
1
GASIFIER
3
REGENERATOR
4
33
34
TO STACK
AIR
BAGHOUSE
25
27
26
28
AIR
SPENT LINE COOLER
TO RECYCLE GAS BLOWER
24
SULFUR RECIRCULATION TANK
BAGHOUSE
30
TO ATMOSPHERE
FILTER
29
SPENT LINE HOPPER
BIN ACTIVATOR
TO DISPOSAL TRUCK
TO ATMOSPHERE
36
BAGHOUSE
AIR
AIR
38
TO ATMOSPHERE
PNEUMATIC FEED FROM TRUCK
LIMESTONE STORAGE
37
LIMESTONE SURGE HOPPER
35
31
OIL ATOMIZING AIR COMPRESSOR
AIR
32
MAIN AIR BLOWER
RECYCLE FLUE GAS AND TAIL GAS
TAIL GAS FROM REDOX TM
BAGHOUSE
LIME DISCHARGE
RECIRCULATED FLUE GAS FROM BOILER
AIR
FUEL OIL FILL PUMP
FUEL OIL TANK
FUEL OIL STRAINER

Figure 3. Unit operations flow diagram of the Foster-Wheeler CAFB demonstration plant.

## TABLE 2. MASS FLOW RATES FOR FOSTER-WHEELER 22 MW CAFB DEMONSTRATION PLANT

| Process stream | Mass flow rate | | Temperature | |
|---|---|---|---|---|
| | kg/sec | lb/hr | °C | °F |
| 1. Limestone to gasifier | 0.06-0.11 | (450-900) | | |
| 2. Product gas to boiler | 10.1-11.4 | (80,000-90,000)* | 871 | (1,600) |
| 3. Gasifier to regenerator stone transfer | 3.15-4.41 | (25,000-35,000) | | |
| 4. Regenerator to gasifier stone transfer | 3.15-4.41 | (25,000-35,000) | | |
| 5. Regenerator off-gas: total | 0.50-0.57 | (4,500-4,500) | 1,038 | (1,900) |
| $SO_2$ | | | | |
| $CO_2$ | | | | |
| $N_2$ | | | | |
| 6. Cyclone solids from regenerator to spent lime cooler baghouse | | | | |
| 7. Water and steam to off-gas cooler | | | | |
| 8. Off-gas from cooler to RESOX$^{TM}$ | | | 649 | (1,200) |
| 9. Air to inert gas generator | 0.67[†] | (5,300) | | |
| 10. Natural gas to inert gas generator | 0.05[†] | (360) | | |
| 11. Cooling water for inert gas generator | 22.7[†] | (180,000) | | |
| 12. Air to RESOX$^{TM}$ | | | | |
| 13. Combined gas to RESOX$^{TM}$ | | | | |
| 14. Anthracite coal to RESOX$^{TM}$ | | | | |
| 15. RESOX$^{TM}$ ash to storage | | | | |
| 16. Elemental sulfur from RESOX$^{TM}$ to sulfur tower | | | 538[†] | (1,000) |
| 17. Drainage from sulfur tower | | | | |
| 18. Steam to sulfur tower | | | | |
| 19. Water to steam drum | | | | |
| 20. Startup steam to sulfur cooler and steam drum | | | | |
| 21. Steam purge from steam drum | | | | |
| 22. Blowdown from steam drum and sulfur cooler | | | | |
| 23. Sulfur discharge | | | 154[†] | (310) |
| 24. RESOX$^{TM}$ tail gas | | | 160[†] | (320) |
| 25. Spent solids from regenerator to cooler | 0.02[†] | (122) | 1,038[†] | (1,900) |
| 26. Air to spent lime cooler | | | | |

(Continued)

TABLE 2 (continued).

| Process stream | Mass flow rate | | Temperature | |
|---|---|---|---|---|
| | kg/sec | lb/hr | °C | °F |
| 27. Spent lime cooler vent to baghouse | | | | |
| 28. Spent lime from cooler to hopper baghouse | | | | |
| 29. Spent lime from baghouse to spent lime hopper | | | | |
| 30. Air emissions from spent lime hopper baghouse | | | | |
| 31. Recycle flue gas and tail gas to gasifier and regenerator | | | | |
| 32. Air to gasifier and regenerator | 6.52-6.58 | (51,700-52,200) | | |
| 33. Combined air/flue/tail gas to gasifier | 7.94 | (63,000) | | |
| 34. Combined air/flue/tail gas to regenerator | | | | |
| 35. Fuel oil to gasifier (if used) | | | | |
| 36. Air emissions from limestone storage baghouse | | | | |
| 37. Fugitive emissions from limestone handling | | | | |
| 38. Air emissions from limestone surge hopper baghouse | | | | |
| 39. Air emissions from coal storage silo baghouse | | | | |
| 40. Fugitive emissions from coal handling | | | | |
| 41. Air emissions from coal surge hopper baghouse | | | | |
| 42. Lignite feed to gasifier | 3.15 | (25,000) | | |
| 43. Air emissions from RESOX$^{TM}$ coal storage baghouse | | | | |
| 44. Air emissions from main stack | | | | |

[*] Assuming flue gas recirculation to gasifier.

[†] Design capacity quantities based on Foster-Wheeler CAFB demonstration plant design drawings.

## REFERENCES

1. Werner, A. S., C. W. Young, M. I. Bornstein, R. M. Bradway, M. T. Mills, and D. F. Durocher. Preliminary Environmental Assessment of the CAFB. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/7-76-017. October 1976. 324 pp. (NTIS No. PB 262-001/AS).

# SECTION 4

# MEASUREMENT PROGRAM

## INTRODUCTION

The experimental phase of the CAFB Environmental Assessment was designed to conform to the data and procedural requirements of an environmental assessment as defined by Level I of EPA's Phased Approach[1] and to provide data comparable to those acquired for the oil-fired study. Data on some internal process streams were also collected to assist in control design and implementation.

As noted previously, the measurement program emphasized emissions from the flue gas, although samples from the fuels, solid waste and process cyclones were also collected. The flue gas was sampled with SASS,* modified RAC, and in-stack impactor trains. The use of these three systems allowed comparison of total particulate collected by SASS and Method 5[2] RAC trains, and particle size distribution as determined by SASS and impactor. Tenax resin, used in a module incorporated into the Method 5 train, provided a measure of gaseous organic emissions in addition to those collected by XAD-2 resin in the SASS.

Organic analyses of SASS, Tenax, and solid samples followed the Level I procedures based on gas chromatography, liquid chromatography, and infrared spectroscopy. Level I inorganic analyses were based on spark source mass spectrometry, atomic absorption spectroscopy, and wet chemistry. Additional particulate analyses were performed with X-ray photoelectron spectroscopy.

This section presents the sampling and analytical procedures used in the measurement program and summarizes the field and laboratory results. Detailed field results are tabulated in Appendix C and laboratory results in Appendix D.

## FIELD TESTS

### Protocol

Field sampling of the ERCA CAFB pilot operation was conducted from January 24 through January 27, 1978. Testing was designed as a Level I Environmental Assessment of the flue gas and particulate emissions. Additionally, solid waste effluents, coal and limestone feeds and internal particulate and solid samples were collected for laboratory analysis. The principal purpose of the testing was to characterize the physical and chemical parameters of the stack emission through onsite analysis of specific chemical species and by the collection of flue gas samples for further laboratory analysis.

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*SASS - Source Assessment Sampling System.

The flue gas was sampled in the stack through the three ports installed approximately 6 diameters upstream from the flue gas entry into the stack. The ports were spaced 120 degrees apart and included two with a 3-inch BSP and one with a 5-inch BSP fitting. Multiple ports were necessary to allow simultaneous testing.

In-stack testing was by SASS train, Andersen impactor, modified RAC train, and integrated bag sampler. In addition to trains used for the chemical and particulate emissions testing, the physical parameters of the flue gas were measured by initial pitot traverses. In-stack thermocouples were used to monitor flue gas temperatures, and the flue gas moisture was determined by gravimetric analysis of moisture gain in the sampling trains. The results of the calculated physical parameters were used to determine the required nozzle sizes and sampling rates for the subsequent in-stack tests.

Particulate sampling was accomplished using a Method 5 train and a SASS train. The Method 5 train was also used to test simultaneously for $SO_2/SO_3$ by Method 8[3] in three of the five RAC train tests. The other two RAC tests used modified trains for the purpose of collecting gaseous organic species as well as total particulate.

Gaseous organic species were collected by the addition of a gas adsorbent column, shown in Figure 4, to the RAC train. This column contained preconditioned Tenax-GC, a porous polymer compound with the ability to adsorb organics heavier than $C_6$. In the modified RAC train the flue gas, after passing through the particulate filter, was cooled to slightly above its dewpoint by means of a thermostated cooling bath and water jacket. The gas then passed through the adsorbent cell which collected the organic constituents. Any condensate which filters through the cell was collected in a glass receiver (not shown). After completion of the sampling, the complete adsorbent column was capped and returned to the laboratory for extraction and analysis. Any condensed liquid can also be extracted and analyzed for organics. This modified train thus provided a sampling method for both organics and total particulate.

The SASS train, which is the train specified in the Level I assessment, also provides both particulate and organic testing of flue gas emissions. In addition, the SASS train allows determination of the particulate size distributions and also provides samples for inorganic analyses of volatiles in the flue gas emissions. For this program, two tests by SASS train were conducted. The methods used were according to those specified by the Level I Manual. A description of the SASS train and its operation may be found in that document. All SASS samples were recovered in the field laboratory provided by ERCA and then prepared for shipment to GCA's laboratory for analysis.

It was necessary to perform in-field analyses of the volatile gases. The tests for these included the Method 8 testing for $SO_2/SO_3$, gas chromatography analysis of hydrocarbons ($C_1$-$C_6$) and fixed inorganic gases, and chemiluminescent analysis of NO-$NO_x$ emissions.

The Method 8 sampling was included with three of the particulate tests by modification of the standard RAC train. All solutions and standardizations

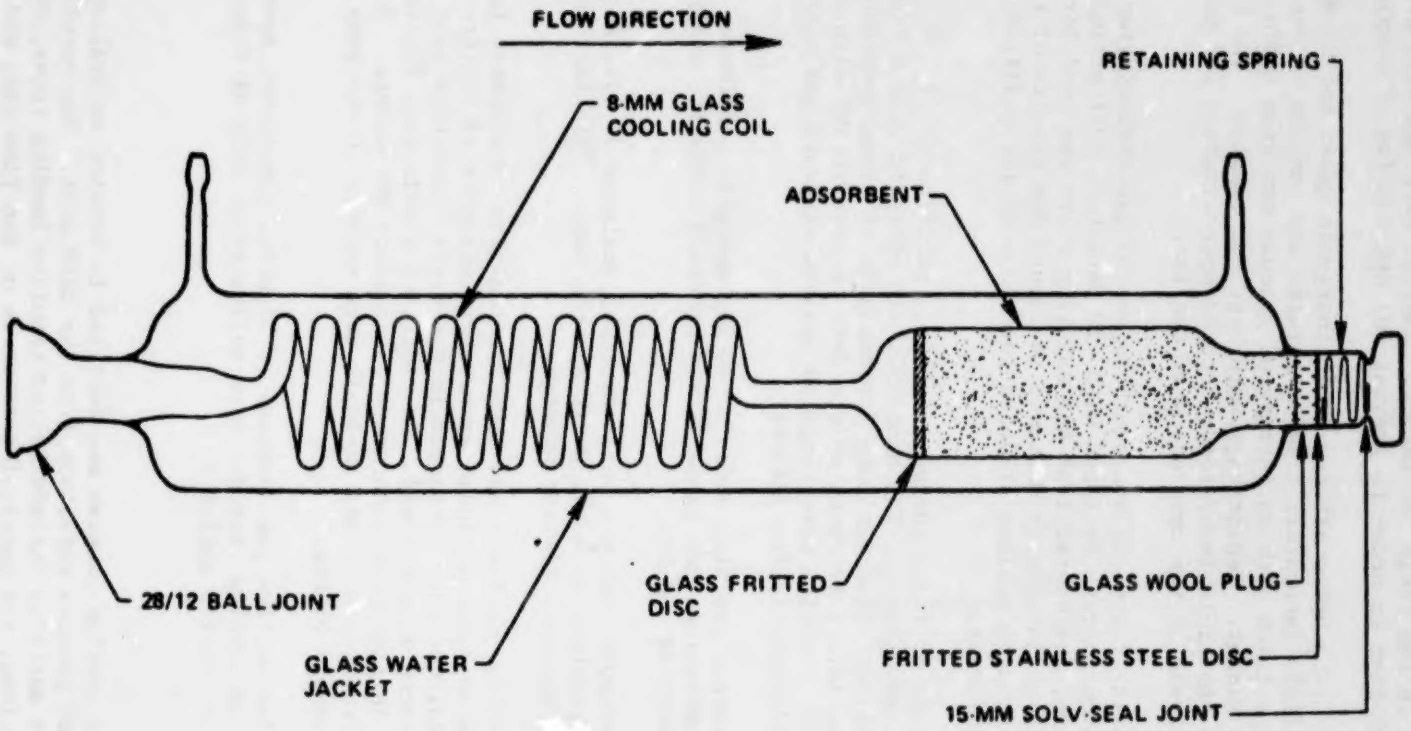
FLOW DIRECTION
8-MM GLASS COOLING COIL
ADSORBENT
RETAINING SPRING
28/12 BALL JOINT
GLASS WATER JACKET
GLASS FRITTED DISC
GLASS WOOL PLUG
FRITTED STAINLESS STEEL DISC
15-MM SOLV-SEAL JOINT

Figure 4. Adsorbent sampling system.

were performed in the field laboratory. Samples were analyzed after the completion of each test in order to prevent any degradation of samples.

Tests for $C_1$-$C_6$ hydrocarbons, fixed inorganic gases and NO-$NO_x$ were performed in the field laboratory from integrated bag samples of the flue gas. Bag samples were taken with an integrated gaseous sampling train as described in the Level I Manual. Tedlar bags were used for samples. The bags were transported to the field laboratory, located approximately 100 yards from the stack, for analysis at the completion of the test.

Field testing for $C_1$-$C_6$ hydrocarbons was by gas chromatography. A Model 511 AID gas chromatograph equipped with FID detector, 6-ft stainless steel Poropak Q column, and heated 1-mℓ gas sampling valve was used for analysis. A recorder with an integrator was used to record the results of the analysis. Samples were compared against standard gas mixtures for qualitative and quantitative analysis.

The analysis of fixed inorganic gases, specifically $CO_2$, $O_2$, $N_2$ and CO, was by gas chromatography. The Model 511 AID equipped with a TCD detector and a 1-mℓ sampling valve was used for analysis of these components. The columns used in this instrument were a 2-ft chromosorb 102 with a 4-ft 13X molecular sieve. Samples were compared against standard gas mixtures for qualitative and quantitative analysis.

The bag sample was also used for NO-$NO_x$ analysis. A Thermo Electron Model 10AR Chemiluminescent gas analyzer provided immediate analysis of the flue gas for both NO and $NO_x$.

It was intended that gas chromatography analysis of $H_2S$, $SO_2$, and COS by a flame photometric detector would also be used. This instrument was inoperative during this testing program.

When possible, analysis was performed on site to minimize transportation losses. These analyses included gravimetric analysis of filters and washes. The $SO_2/SO_3$ analyses were performed in the field laboratory with standard solutions prepared in the field. As described previously, the bag samples were analyzed in the field laboratory for gaseous components. Samples requiring more complex treatment and analysis were shipped to the home laboratory along with suitable blanks.

In addition to flue gas, samples of lignite, limestone, spent stone, gasifier bed, and cyclone catches were collected by ERCA at 6-hour intervals and provided to GCA for analysis.

## Results

The field testing program was designed to provide an evaluation of the particulate and gaseous emissions from the CAFB unit. The results obtained from the field analysis include the particulate loading rates, the particulate size distributions, the physical parameters of the flue gas, and the gas analysis.

The data shown in Table 3 provide results of physical parameters from the two tests with the SASS train and the five tests with the modified RAC trains. The moisture determinations were obtained from gravimetric analysis of the moisture gain of each train. The reason for the variation in these values is unknown, but it should be noted that the exact temperature control and high volume of the SASS train would possibly provide a more representative value than the RAC values.

Particulate loadings as obtained from gravimetric analysis of the filter, cyclones, and washes of each test are also included in Table 3. There is some variation in the comparison of these results between trains which would be expected since each train was a single point sample. Also, it should be noted that while RAC train tests and SASS train tests were run simultaneously when possible, the test time duration and volume of gas sampled were significantly different. The results of these tests do provide an indication of the particulate loadings for the CAFB unit. The values obtained translate into 2 to 4 $lb/10^6$ Btu for total emissions.

The results of the particulate sampling by SASS train also provide a characterization of the particle size distributions. The results of this breakdown, along with the other measured parameters for each test, are included in Table 4.

The SASS train particle size distribution results are shown graphically in Figure 5. These graphs were obtained using the calculated cut diameters for each cyclone as determined by the cyclone equation $D_{P2} = D_{P1}\sqrt{\frac{\mu_2 Q_1}{\mu_1 Q_2}}$ where $D_{P1}$ is calibrated aerodynamic particle diameter for $Q_1 = 6.41$ acfm at $400^oF$ and $\mu_1 = 0.026$ centipoise. The values for the percent weight were obtained from the values reported in Table 4, as calculated from the total particulate for each cyclone.

The results of the particle size distribution calculations indicate that 98 percent of the particulate was greater than 1 μm, with the mean particle diameter between 6 and 7 μm. These results show good correlation to the results of the three in-stack Andersen impactor runs which are presented by the conventional log normal plots of the particle size distributions shown in Figure 6.

Field analyses were also performed for gaseous species in the flue gas. As described previously, the RAC train was modified to provide determinations of $SO_2$ and $SO_3$. The measured parameters for these three tests are found in Table 3, and the results of the field analyses are included in Table 5.

Table 5 also includes the results of the field analyses of the bag samples. The bag samples were taken simultaneously with the train sampling on 3 of the 4 test days. The results of the fixed gas analysis show a large degree of variation presumably due to changes in operating conditions. The value for $O_2$ reported on January 27 appears abnormally low, but a check of calculations shows closed deviation of less than 3 percent.

TABLE 3. CAFB PARTICULATE TEST DATA

| Test No. | Date | $Q_s$[*] (dscfm) | $Q_a$[†] (acfm) | Moisture (%) | E.A.[‡] (%) | Part. loading (gr/dscf) | $V_{mstd}$[§] (dscf) | Test design |
|---|---|---|---|---|---|---|---|---|
| RAC-1 | 1/24 | 1200.7 | 1463.3 | 7.1 | 39.9 | 1.0381 | 29.525 | Part.; $SO_2/SO_3$ |
| SASS-1 | 1/24 | 1100.3 | 1590.0 | 10.0 | 53.6 | 0.9632 | 919.167 | SASS |
| RAC-2 | 1/25 | 1388.1 | 1891.6 | 6.6 | 67.1 | 1.5291 | 32.740 | Part.; organics |
| SASS-2 | 1/26 | 1271.6 | 1878.0 | 12.1 | 53.6 | 1.1994 | 266.291 | SASS |
| RAC-3 | 1/26 | 1346.7 | 1844.6 | 9.0 | 53.6 | 0.9906 | 32.876 | Part.; $SO_2/SO_3$ |
| RAC-4 | 1/27 | 1422.7 | 1972.8 | 4.5 | 29.4 | 0.8520 | 26.318 | Part.; organics |
| RAC-5 | 1/27 | 1053.8 | 1536.0 | 9.4 | 28.0 | 0.7917 | 24.630 | Part.; $SO_2/SO_3$ |

[*] $Q_s$ - Stack flow rate at dry standard conditions.

[†] $Q_a$ - Stack flow rate at actual stack conditions.

[‡] E.A. - Calculated excess air.

[§] $V_{mstd}$ - Volume of flue gas sampled at dry standard conditions.

TABLE 4. CAFB PARTICULATE MASS AND SIZE EMISSIONS DATA MEASURED BY SASS TRAIN

SASS-1

| Parameter | Rate or value |
|---|---|
| Flue gas flow rate | 1100.3 dscfm |
| Temperature at sampling port | 214°F |
| Flue gas moisture | 10.0% |
| Total particulate loading | 0.9632 gr/dscf |
| **Particle size fraction collected** | **Percent of total particulates** |
| < 1 μm (filter) | 1.2% |
| > 1 μm | 26.9% |
| > 3 μm | 50.3% |
| > 10 μm | 21.6% |

SASS-2

| Parameter | Rate or value |
|---|---|
| Flue gas flow rate | 1271.6 dscfm |
| Temperature at sampling port | 214°F |
| Flue gas moisture | 12.0% |
| Total particulate loading | 1.1994 gr/dscf |
| **Particle size fraction collected** | **Percent of total particulates** |
| < 1 μm (filter) | 1.8% |
| > 1 μm | 31.8% |
| > 3 μm | 44.1% |
| > 10 μm | 22.4% |

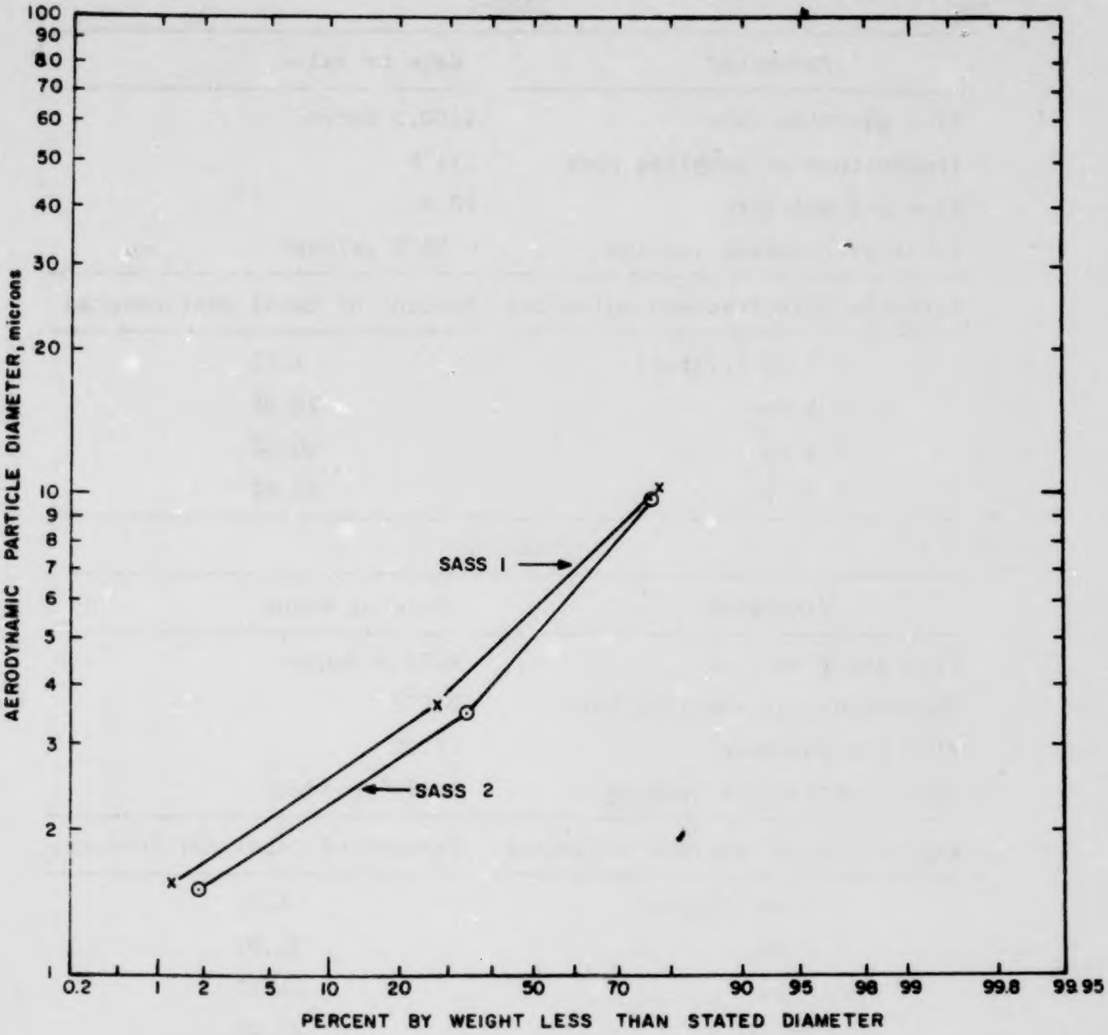

Figure 5. Particulate size distributions measured by SASS train.

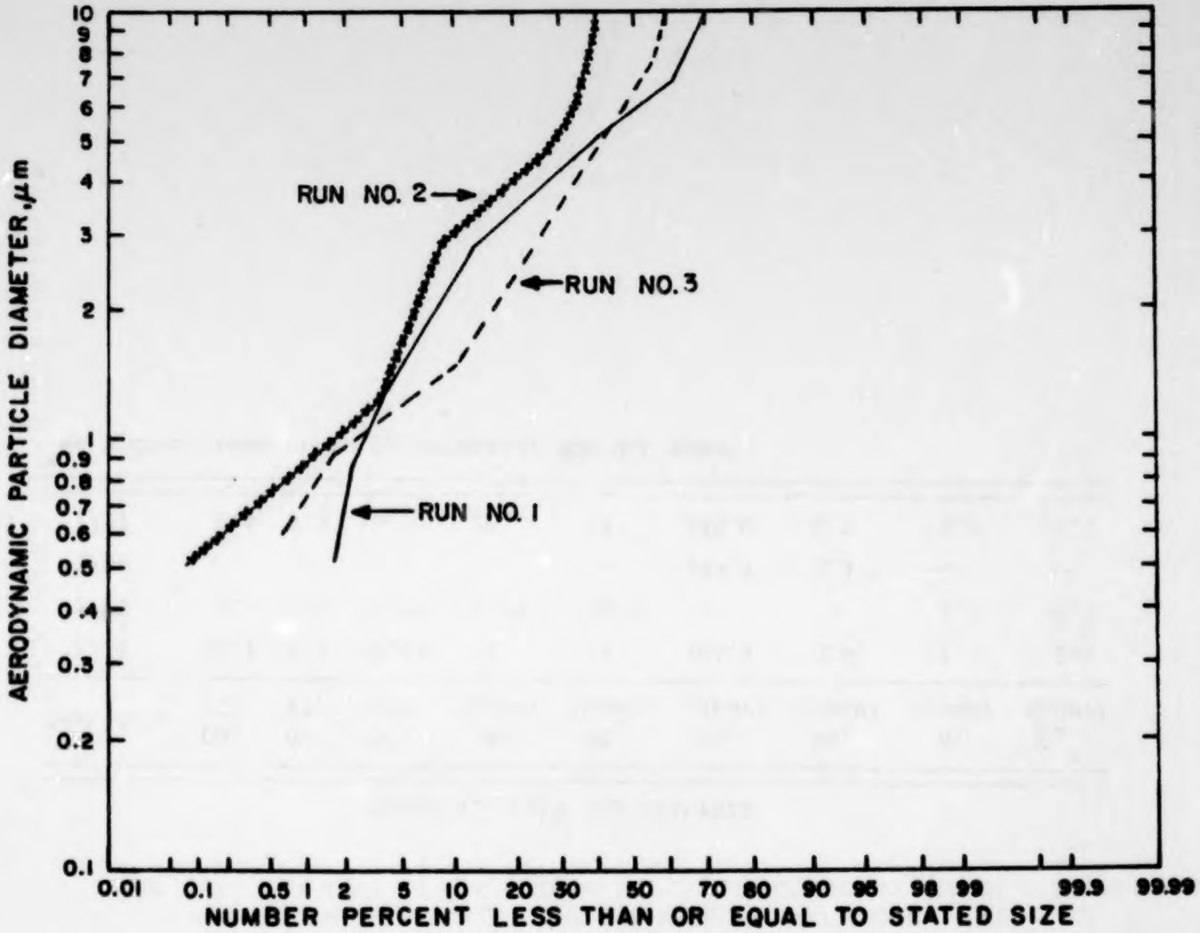

Figure 6. Particulate size distributions measured by in-stack impactor.

TABLE 5. CAFB GAS ANALYSIS

| Test date | $CO_2$ (%) | $O_2$ (%) | CO (%) | NO (ppmv) | $NO_x$ (ppmv) | $SO_2$ (ppmv) | $SO_3$ (ppmv) | $C_1$ (ppmv) | $C_2$* (ppmv) |
|---|---|---|---|---|---|---|---|---|---|
| 1/24 | 10.1 | 9.1 | <0.05 | 28 | 33 | 101.9 | 0.8 | 21.4 | 2.8 |
| 1/25 | 6.1 | 9.0 | <0.05 | 14.5 | 15.7 | — | — | 6.5 | <0.5 |
| 1/26 | — | — | — | — | — | 299.7 | 1.3 | — | — |
| 1/27 | 6.4 | 5.3 | <0.05 | 26 | 42 | 185.0 | 0.9 | <0.5 | <0.5 |

*No hydrocarbons above $C_2$ detected, MDL 0.5 ppmv.

The results of hydrocarbon analysis on January 24 showed detectable hydrocarbons in the $C_1$ and $C_2$ boiling point range as determined according to the Level I method. The values of detectable hydrocarbon appeared to decrease during the testing, with no hydrocarbons detected above the 0.5 ppmv detectability limit of the instrument for the third bag sample taken January 27.

The values for NO and $NO_x$ reported in Table 5 were obtained from analysis of bag samples by chemiluminescent instrument. The instrument was standardized against a standard NO gas and checked for standardization after being returned to the home laboratory. The results shown for the test on January 25 are abnormally low and may be the result of sample degradation due to a long holding time between sampling and analysis. Recent data gathered by other EPA contractors indicate that NO and $NO_x$ collected in aluminized bags from streams containing air and moisture can degrade by a factor of 2 after a few hours. The runs completed on January 24 and January 27 were each analyzed within 2 hours of collection. Although Tedlar, not aluminized, bags were used in this study, it is possible that the $NO/NO_x$ values reported in Table 5 could be low by as much as a factor of 2.

## Discussion

The testing program was designed to comply with the EPA definition of an environmental assessment for the CAFB operation. In addition to the defined Level I environmental assessment, a number of other testing methods were included in this program to provide additional information on the physical and chemical properties of the emissions from the process.

Field tests with the RAC train and the SASS train were conducted simultaneously so that measurements could be compared. The results of the reported particulate loadings showed a variance of 4 percent and 12 percent for the tests No. 1 and No. 2. This variation is possibly due to the fact that SASS sampling was at a single point while RAC test No. 1 was traversed over 12 points. It was not possible to traverse with RAC test No. 2 since the addition of the organic sampling column prohibited the movement of the train. Sampling for RAC test No. 2 was thus at a single point.

The organic sampling column which was adapted to the RAC train used Tenax-GC as the organic adsorbent. The SASS train which is also designed to collect organic emissions used XAD-2 resin as the collection medium. This design allowed the comparison of the efficiencies of the two organic collecting resins. The result of this comparison is discussed in the Laboratory Analysis discussion of this report.

In addition to the organic emissions and total particulate emissions testing, the SASS train provided particle size information analysis of the three cyclone catches. These results, which are reported in the field analysis section, were compared to the particle size information which was obtained using Andersen impactors. The results of the two test designs showed good agreement with regard to size distributions and mean particle diameter.

The test program had been designed to provide comparison of sulfur species analysis methods. Unfortunately, the flame photometric gas chromatograph was inoperative, and the results reported for $SO_2$ and $SO_3$ species were derived solely from the modified RAC train sampling.

There were other problems during the sampling program which required the alteration of the original plan. A principal problem was the sporadic operation of the CAFB unit, which resulted in schedule changes and shorter than specified SASS train sampling run time. The number of intended RAC train runs was reduced due to the changes in unit run schedule.

Other problems which were independent of the CAFB operation also caused delays and alteration of the intended schedule. Primary among these was the problem of power supply for the test equipment and laboratory instruments. Power for all of these instruments was provided by gasoline-powered generators. During testing one of the four generators was inoperative due to a short in the generator windings. As a result, the power supply for the laboratory was available only when one of the other three generators was not needed for the sampling equipment. This problem resulted in delays in some analyses performed by gas chromatography and $NO_x$ analyzer.

Other problems were encountered during the test program, but on-site modifications and the cooperation of CAFB personnel remedied these situations to the satisfaction of the intent of the test program. The overall goals of program design were completed and the results reported are considered representative of the CAFB unit at the conditions tested.

## LABORATORY ANALYSIS

### Analysis Protocol

The laboratory analysis program was designed to characterize particulate and gaseous emissions from the CAFB pilot plant during operations with lignite. Using the Level I procedures for an environmental assessment as the framework for the analytical scheme, a program was developed which provided information on the CAFB process as well as information for an environmental assessment.

The types of sample analyses carried out are summarized in Table 6. SASS samples were analyzed for organics and inorganics by Level I methods with the exception that particulate samples were not combined (i.e., filter with 1μ cyclone, 3μ cyclone with 10μ cyclone). This provided a more complete analysis of the particulate size fractions which it was hoped would reveal information on their origin. Bulk samples were also analyzed by Level I methods to determine the composition of solid wastes generated by the CAFB and to provide information on the process which may aid in the design of controls.

Samples collected using the modified RAC train, in which particulate on a filter and gaseous organics on Tenax-GC resin were collected, were analyzed as shown. Because our experience has shown that most organic emissions are found on the resin samples, the particulate catches from RAC runs 1 to 5 were combined separately for organic compounds; therefore, a composite sample was made. Similarly, no inorganic analyses were performed on the Tenax resin. Two particulate samples were analyzed separately for bulk elemental composition.

**TABLE 6. LABORATORY ANALYSIS PLAN FOR CAFB-LIGNITE STUDY**

Organic Analysis

- SASS samples
  - Particulate
  - Resin (XAD-2)
  - Condensate
  - Rinses
- RAC samples
  - Particulate (composite of probe rinses; runs 1 to 5)
  - Tenax (runs 2 and 4)
- Bulk samples
  - Spent solids

Inorganic Analysis

- SASS samples
  - Particulate
  - Resin (XAD-2)
  - Condensate
  - Impingers
  - Rinses
- RAC samples
  - Particulate (runs 1, 3 and 5)
- Bulk samples
  - Lignite
  - Limestone
  - Spent solids
  - Cyclone fines
  - Gasifier bed

Surface Analysis

- SASS samples
  - Particulate
- RAC samples
  - Particulate
- Impactor substrates

Organic Analyses--

Level I organic analysis is designed to provide a semiquantitative (± 3×) determination of the classes and concentrations of organic substances contained in waste streams emitted by stationary energy and industrial processes. In this study, particulate, flue gas and solid waste were analyzed for organics.

In general, three categories of organic compounds are defined by Level I: gaseous, volatile and nonvolatile. Volatile organics are defined as those which boil between 90° and 300°C; nonvolatile organics boil above 300°C, and gaseous organics boil below 90°C. Gaseous organics which are measured in the field have been discussed earlier. Organic analyses were performed on all SASS train components except the impingers. All stainless steel components were rinsed with methylene chloride or a 50-50 (v/v) mixture of methylene chloride with acetone to recover organics. Organics in the condensate, particulate and XAD-2 resin were recovered by methylene chloride extraction. Tenax resin was extracted with pentane.

Because the extracts, in general, are too dilute to detect organic compounds using almost any instrumental technique available, all organic liquid and solvent extracts were concentrated to 10 mℓ via a Kuderna-Danish (K-D) concentrator. (The Kuderna-Danish concentrator is a glass apparatus which removes most of the solvent while minimizing the loss of the other volatile components.)

The concentrated samples were analyzed in two stages. The first stage of the analysis consists of four different methods. A sample aliquot is evaporated to dryness and weighed. The residue is then transferred to KBr plates and analyzed by a grating infrared spectrophotometer. The output of these steps is a measure of the amount of nonvolatile organic matter present in each sample and an indication of the functional groups which are present.

Another sample aliquot is injected into a gas chromatograph (GC). The instrument is calibrated so that the organic compounds boiling between 90° and 300°C (i.e., the total chromatographic organics or TCO) are quantified relative to n-decane. If the TCO is greater than 75 $\mu g/m^3$, the quantity of organics boiling within certain ranges is also determined. The volatile organics boiling within the ranges 90° to 110°, 110° to 140°, 140° to 160°, 160° to 180°, 180° to 200°, 200° to 220°, 220° to 240°, 240° to 260°, 260° to 280°, and 280° to 300°C were quantified relative to n-decane and reported as $C_7$, $C_8$, $C_9$, $C_{10}$, $C_{11}$, $C_{12}$, $C_{13}$, $C_{14}$, $C_{15}$ and $C_{16}$ alkane equivalents. The difference in the response of the GC detector between decane and the other hydrocarbons has been shown to be ±5 percent, which is well within the accuracy requirements of Level I analysis. The samples were not analyzed further if the total quantity of volatile and nonvolatile organic emissions (the sum of the TCO emissions and the gravimetric components) was less than 0.50 $mg/m^3$.

In the second stage of analysis, those samples with organic emission factors larger than 0.50 $mg/m^3$ were fractionated by liquid chromatography (LC). (The LC method used provides some separation of components according to polarity.) A sample aliquot was transferred to the top of a liquid chromatographic column packed with 6.5 gm silica gel in pentane. The column was developed by gradient elution using the solvents given in Table 7, and seven fractions were collected. The fractions were analyzed by the gravimetric and infrared methods described previously. If the unfractionated sample contained more than 10 percent volatile organic material, each fraction was also analyzed by the gas chromatographic method discussed above.

TABLE 7. SOLVENTS USED FOR LIQUID CHROMATOGRAPHY

| Fraction | Solvent |
|---|---|
| 1 | 25 mℓ pentane |
| 2 | 10 mℓ 20% $CH_2Cl_2$/pentane |
| 3 | 10 mℓ 50% $CH_2Cl_2$/pentane |
| 4 | 10 mℓ $CH_2Cl_2$ |
| 5 | 10 mℓ 5% $CH_3OH/CH_2Cl_2$ |
| 6 | 10 mℓ 20% $CH_3OH/CH_2Cl_2$ |
| 7 | 10 mℓ 50% $CH_3OH/CH_2Cl_2$ |

Inorganic Analysis--

Level I inorganic analysis consisted of a Spark Source Mass Spectrographic (SSMS) elemental survey along with specific analyses for mercury, fluoride, chloride, and sulfate. Both liquid and solid samples were received in the laboratory for analysis. Organic materials, both liquid and solid, were combusted in a Parr oxygen bomb to destroy the organic matrix. Solids that were primarily inorganic (with the exception of glass fiber particulate filters) were analyzed directly by SSMS, but were digested with aqua regia for mercury and fluoride analyses. Particulate filters were generally acid digested for the SSMS analysis as well, because of the cohesion and sparking problems that are associated with having glass filters in the graphite electrodes. All particulate samples for SSMS were run neat whenever possible. Samples for chloride and sulfate analysis were prepared by extraction with hot water. Table 8 summarizes the inorganic sample preparation scheme.

Mercury was analyzed by a cold vapor AA technique. The sulfate determination was a turbidimetric procedure and specific ion electrodes were used to analyze both fluoride and chloride. These analyses are described further in the following paragraphs.

Spark Source Mass Spectrography (SSMS)--SSMS was used to perform a semi-quantitative elemental survey analysis on the Level I samples taken. The analysis was performed using a JEOL Analytical Instruments, Inc. Model JMS-01BM-2 Mass Spectrograph. The JMS-01BM-2 is a high resolution, double focusing mass spectrometer with Mattauch-Herzog ion optics. The instrument is specially designed to carry out high sensitivity trace element analysis with the aid of an RF spark ion source and photoplate detection. An aliquot of each sample to be analyzed is incorporated into two electrodes which are

TABLE 8. INORGANIC SAMPLE PREPARATION SCHEME

| Sample | Preparation | Analysis |
|---|---|---|
| Particulate filters | Aqua regia extraction | SSMS, Hg, $F^-$ |
| | Hot water extraction | $SO_4^=$, $Cl^-$ |
| Cyclone catches | Neat | SSMS |
| | Aqua regia extraction | Hg, $F^-$ |
| | Hot water extraction | $SO_4^=$,$Cl^-$ |
| Composite[*] | None required | SSMS, Hg, $F^-$, $Cl^-$ |
| XAD-2 resin | Parr bomb | SSMS, Hg, $F^-$, $Cl^-$, $SO_4^=$ |
| Impinger composite[†] | None required | Hg |
| Bulk samples | | |
| Lignite | Parr bomb | SSMS, Hg, $F^-$, $Cl^-$, $SO_4^=$ |
| Others | Aqua regia extraction | SSMS, Hg, $F^-$ |
| | Hot water extraction | $SO_4^=$, $Cl^-$ |

[*] Composite of peroxide impinger, condensate, and acid module rinse.

[†] Composite of second and third impingers.

then mounted in the ion source of the mass spectrometer. These electrodes are "sparked" with a high voltage discharge which decomposes and ionizes the electrode material. Because of the high energy of the electrical discharge, most of the material is reduced to its elemental form. The ions formed are collected with focusing plates and subsequently measured in the mass spectrometer. Spark source mass spectrometry can be used to detect elemental concentrations down to $10^{-9}$ g (one nanogram). Although the sensitivity may vary somewhat from sample to sample, practically all elements (except H, C, N, O, and the inert gases) in the periodic table can be detected.

Interferences can result from the formation of multiply charged ions, ion clusters and molecular ions such as oxides, hydrides, hydroxides, and carbides. These interferences, coupled with the fact that the discharge conditions in the ion source are not easily reproduced, limit the accuracy of the technique. Spark source mass spectrometry, however, is very useful as a survey tool, and is capable of providing semiquantitative results (i.e., accurate to within a factor of 2 or 3).

Mercury - cold vapor--The cold vapor mercury analysis is based on the reduction of mercury species in acid solution with stannous chloride and the subsequent sparging of elemental mercury, with nitrogen, through a quartz cell where its absorption at 253.7 nm is monitored.

Sulfate - turbidimetric--The basis of the analysis is the formation of a barium sulfate precipitate in a hydrochloric acid medium with barium chloride in such manner as to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension was measured by a transmission photometer and the sulfate ion concentration determined by comparison of the reading with a standard curve.

Fluoride--Fluoride was determined potentiometrically using a selective ion fluoride electrode in conjunction with a standard single junction sleeve-type reference electrode and a pH meter having an expanded millivolt scale. Sample pH was between 5 and 9. Polyvalent cations of $Si^{+4}$, $Fe^{+3}$ and $Al^{+3}$ interfere by forming complexes with fluoride. The addition of a pH 5 total ionic strength adjustor buffer (TISAB II) containing a strong, chelating agent preferentially complexes aluminum (the most common interference), silicon, and iron and eliminates the pH problem.

The addition of TISAB II also provides a high total ionic strength background to help mask the difference in total ionic strengths between samples and standards. However, the TISAB II cannot entirely compensate for this difference due to the very high and variable level of ionic strength in the Level I SASS samples. Thus, a known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples.

Chloride--Chloride was determined potentiometrically using a solid state selective ion chloride electrode in conjunction with a double junction reference electrode and a pH meter having an expanded millivolt scale. The solid state electrode is used because it is not sensitive to the higher levels of nitrate, sulfate or bicarbonate which could be present in many of the samples.

This method does require that the sample and standards have the same total ionic strength. Because samples can have a very high and variable level total ionic strength, a known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples.

Surface analyses--Included as part of the analytical scheme of this study is surface analysis by X-ray photoelectron spectroscopy, or ESCA, which is not part of Level I. ESCA is capable of surface ($\leq$ 20Å depth) elemental analysis of solid and particulate samples, with relative amounts of each element being reported as percent atomic. ESCA can also give information on the oxidation states of a number of elements, a capability which was applied to the study of carbon and sulfur species in this program. Coupled with the use of argon ion etching to remove surface layers, ESCA can provide profiling to supplement surface and SSMS bulk analyses. Further information on the technique is provided in the report of the CAFB-fuel oil study.[4]

## Results of Laboratory Analyses

### Organic Results--

To determine organic flue gas emissions, samples collected by both SASS and RAC trains were analyzed. Table 9 summarizes the volatile, nonvolatile and total organic emissions determined for SASS runs 1 and 2, Tenax RAC runs 2 and 4, and the aggregate content of the five particulate catches from RAC runs 1 to 5. As noted in Table 3, the runs represented by the first four columns in Table 9 were performed on different days, thus precluding any direct comparison between the SASS and RAC-Tenax collection efficiencies.

TABLE 9. TOTAL $>C_6$ ORGANIC EMISSIONS ($\mu g/m^3$)

| | SASS No.1 | SASS No. 2 | Tenax RAC No. 2 | Tenax RAC No. 4 | Particulate RAC Nos. 1-5 |
|---|---|---|---|---|---|
| TCO* | 221 | 307 | 290 | 1,070 | 360 |
| Gravimetric | 565 | 21,725 | 5,050 | 17,200 | 2,540 |
| Total | 786 | 22,032 | 5,340 | 18,270 | 2,900 |

*Total Chromatographable Organics ($C_7$-$C_{16}$ B.P. Equivalents).

The low total organic emissions found in SASS No. 1, relative to the other runs, may be attributable to recycle of fines from the gasifier cyclone to the gasifier. This recycle operation was suspended after SASS No. 1 to alleviate particulate accumulation in the boiler. Although the excess air values for SASS 1 and 2 were identical, the factor of three difference between the $SO_2$ emissions (see Table 5) during these runs indicates that during SASS No. 1 the CAFB was more "chemically active" than during SASS No. 2. The high $C_1$ and $C_2$ emissions determined by gas chromatography during SASS No. 1 may be indicative of more efficient gasification and pyrolysis of heavy lignite organic matter during that run.

Tables 10 and 11 display the distribution of organic emissions among the SASS components for runs 1 and 2. Emissions called individual alkane equivalents refer to compounds boiling in the ranges $C_7$-$C_{16}$. As can also be noted in Table 9, SASS No. 1 has a high proportion of TCO material. Again, this is consistent with the relatively large $C_1$ and $C_2$ values and with the inference that the gasifier was particularly effective during SASS No. 1. Consistent with the oil-fired results, most of the capturable organics are found in the resin module (XAD-2, module rinse and condensate).

Table 12 contains a similar summary of individual alkane equivalents (IAE's), TCO and gravimetric weights for Tenax RAC 2 and 4 and the particulate composite RAC 1-5 samples. As with the SASS samples, a peak in the IAE region occurs around $C_9$. The sizable quantity of extractable organics found in the RAC particulate is somewhat surprising. The composite nature of this sample precludes assignment of high organic emissions to any one run. These results do suggest, however, that higher total organic emissions may have occurred during RAC runs 1, 3 or 4 than during either SASS or Tenax runs.

Infrared spectra of all samples listed in Tables 9 to 12 were obtained to discern the functional groups contained in each sample. All spectra are contained in Appendix D. Tables 13 and 14 contain interpretations of spectra taken of samples comprising SASS 1 and 2. Figures 7 and 8 are spectra of XAD-2 resin extracts from SASS 1 and 2, respectively. The resin extract from SASS No. 1 contains a significant contribution from saturated hydrocarbons while the spectrum contained in Figure 8 is dominated by oxygenated compounds. Summary Tables 13 and 14 show a wide variety of hydrocarbons and heteroatom groups. The inability to obtain meaningful spectra from some particulate extracts may be due to evaporation losses occurring as a result of heat lamp drying of KBr plates. The use of a heat lamp for rapid evaporation of methylene chloride solvent was instituted to prevent condensation of water vapor on the IR plates which would result in masking the spectrum.

Table 15 summarizes the IR interpretations of RAC Tenax and particulate extracts. The groups identified in these samples are similar to those found in the SASS samples. The indication of major amide emissions in the Tenax samples may indicate a higher collection efficiency for these compounds by this resin over XAD-2. Additional experimental work needs to be carried out to determine if this is in fact the case or if amides may be present as impurities in Tenax, more easily extracted by pentane (used with Tenax) than by methylene chloride (used with XAD-2) or formed in secondary reactions.

Three samples met the Level I weight criterion (gravimetric plus TCO) for liquid chromatography (LC) separation: XAD and module rinse from SASS No. 2 and Tenax from RAC No. 4. Tables 16, 17 and 18 list the distribution of material in the seven fractions and the functional groups found by IR in each fraction. From the fractional distributions and functional group identifications shown in these tables it is apparent that esters, ketones and aliphatic hydrocarbons are the principal organic emissions from the CAFB. Following in importance are substituted aromatics and possibly amines, ethers, amides, alcohols, phenols and nitrosubstituted compounds.

TABLE 10. ORGANIC EMISSIONS IN CAFB SASS SAMPLES, RUN No. 1 (μg/m$^3$)

| IAE* | 10μ cyclone | 3μ cyclone | 1μ cyclone | Particulate filter | Probe rinse | XAD-2 resin | Module rinse | Condensate |
|---|---|---|---|---|---|---|---|---|
| 7 | - | - | - | - | - | - | - | - |
| 8 | - | - | - | - | 4.66 | 11.2 | 8.95 | 4.88 |
| 9 | 2.49 | 7.44 | 5.78 | - | - | 2.00 | - | 91.4 |
| 10 | 1.07 | 1.90 | 2.98 | - | - | 22.5 | - | - |
| 11 | - | - | - | - | - | b.r.† | - | - |
| 12 | - | - | - | 0.599 | - | 22.8 | - | 0.232 |
| 13 | - | - | 0.624 | 2.66 | - | 4.57 | - | - |
| 14 | - | - | - | - | - | 7.06 | - | - |
| 15 | - | - | - | 5.39 | 0.131 | 1.26 | - | - |
| 16 | - | - | - | 4.69 | - | 3.60 | - | - |
| TCO | 3.56 | 9.34 | 9.38 | 13.3 | 4.79 | 75.0 | 8.95 | 96.5 |
| Grav. | b.r.† | b.r.† | b.r.† | 28.7 | b.r.† | 467 | 69.3 | b.r.† |
| TO | 3.56 | 9.34 | 9.38 | 42.0 | 4.79 | 542 | 78.3 | 96.5 |

*Individual alkane equivalents.

†b.r. - blank removes; sample less than or equal to blank.

TABLE 11. ORGANIC EMISSIONS IN CAFB SASS SAMPLES, RUN No. 2 ($\mu g/m^3$)

| IAE[*] | 10μ cyclone | 3μ cyclone | 1μ cyclone | Particulate filter | Probe rinse | XAD-2 resin | Module rinse | Condensate |
|---|---|---|---|---|---|---|---|---|
| 7 | - | - | - | - | - | - | 19.4 | - |
| 8 | - | - | - | - | - | - | 6.20 | 9.62 |
| 9 | 6.31 | 31.1 | 6.24 | - | - | - | - | 158 |
| 10 | - | - | - | - | 0.659 | b.r.[†] | - | - |
| 11 | - | - | - | - | 0.838 | b.r.[†] | - | - |
| 12 | - | - | - | - | - | b.r.[†] | - | - |
| 13 | - | - | - | - | - | - | 4.12 | - |
| 14 | - | - | - | - | - | - | - | - |
| 15 | - | - | 14.6 | - | 2.86 | b.r.[†] | 28.3 | 18.4 |
| 16 | - | - | - | - | - | - | - | - |
| TCO | 6.31 | 31.1 | 20.8 | - | 4.35 | b.r.[†] | 58.0 | 186 |
| Grav. | 80.1 | 303 | 102 | b.r.[†] | b.r.[†] | 3240[‡] | 18000[‡] | b.r.[†] |
| TO | 86.4 | 334 | 123 | b.r.[†] | 4.35 | 3240[‡] | 18100[‡] | 186 |

[*] Individual alkane equivalents.

[†] b.r. - blank removes; sample less than or equal to blank.

[‡] Only the first three digits are significant.

TABLE 12. ORGANIC EMISSIONS IN CAFB RAC SAMPLES ($\mu g/m^3$)

| IAE* | Tenax: RAC-2 | Tenax: RAC-4 | Particulate: RAC 1-5 |
|---|---|---|---|
| 7 | - | 5.53 | - |
| 8 | - | - | 28.8 |
| 9 | 41.8 | 230 | 324 |
| 10 | 115 | 731 | - |
| 11 | - | 13.4 | 7.17 |
| 12 | 32.4 | 17.4 | - |
| 13 | 8.53 | - | - |
| 14 | 12.7 | - | - |
| 15 | 82.7 | 60.7 | - |
| 16 | - | 10.5 | - |
| TCO | 290 | 1070 | 360 |
| Grav. | 5050 | 17200 | 2540 |
| TO | 5340 | 18300 | 2900 |

*Individual alkane equivalents.

TABLE 13. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF UNFRACTIONATED SAMPLES, SASS RUN No. 1

| Sample code | Medium | Minor | Trace |
|---|---|---|---|
| XAD-2 resin | Esters,* saturated hydrocarbons | Possible nitrosubstituted compounds, ethers | |
| Condensate | Aliphatic hydrocarbons | Esters,* ketones;* possible: ethers,* organosilicon compounds, nitrocompounds, substituted aromatics | |
| Module rinse | | Esters* | Possible: aliphatic ethers |
| Probe rinse† | | | |
| Particulate filter† | | | |
| 1μ cyclone | | Saturated esters, saturated hydrocarbons | Possible: aryl or unsaturated esters or ethers |
| 3μ cyclone | | | Saturated esters; possible: aryl or unsaturated esters or ethers, organosilicon compounds |
| 10μ cyclone† | | | |

*May be saturated, unsaturated, aryl.

†Blank removes IR spectrum.

TABLE 14. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF UNFRACTIONATED SAMPLES, SASS RUN No. 2

| Sample code | Medium | Minor | Trace |
|---|---|---|---|
| XAD-2 resin | Aryl or unsaturated esters; ketones[*] hydrocarbons | Possible: nitrocompounds, ethers | |
| Module rinse | | Aliphatic hydrocarbons esters;[*] possible: aromatic hydrocarbons | Saturated ketones; possible ethers |
| Condensate | | | Aliphatic ethers |
| Probe rinse | Saturated hydrocarbons, saturated esters | Aryl esters; possible: substituted aromatics, aliphatic ethers | |
| Particulate filter[†] | | | |
| 1μ cyclone[†] | | | |
| 3μ cyclone[†] | | | |
| 10μ cyclone[†] | | | |

[*] May be saturated, unsaturated and/or aryl.

[†] Blank removes IR spectrum.

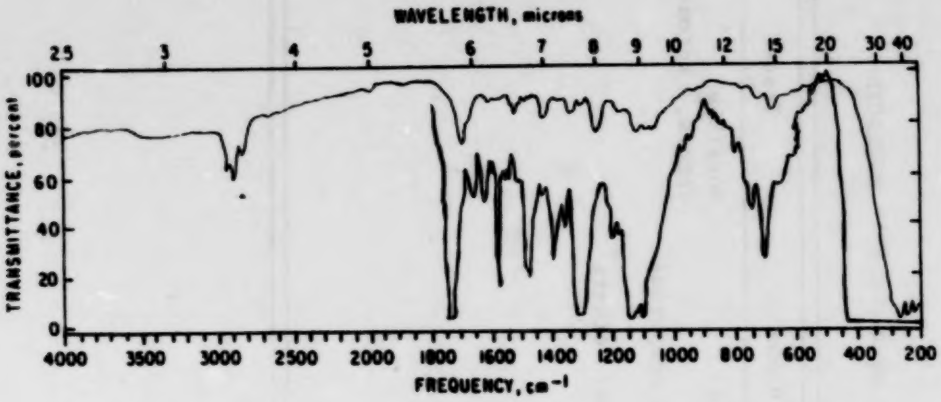

Figure 7. IR spectrum of XAD-2 resin from SASS-1. Major peaks indicate esters, saturated hydrocarbons; possible ethers and nitrosubstituted compounds.

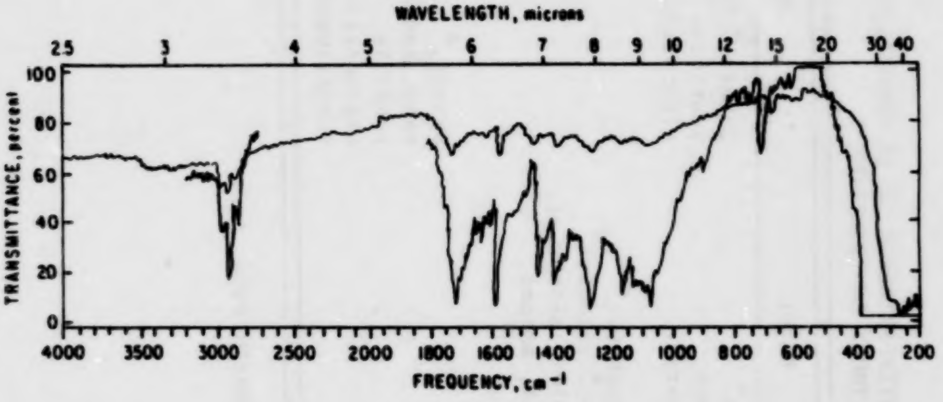

Figure 8. IR spectrum of XAD-2 resin from SASS-2. Major peaks indicate aryl or unsaturated esters, ketones, hydrocarbons; possible ethers and nitrocompounds.

TABLE 15. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF RAC SAMPLE EXTRACTS WITHOUT LC FRACTIONS

| Sample code | Major | Medium | Minor | Trace |
|---|---|---|---|---|
| RAC-2, Tenax | Amides[*] (primary, secondary) | Ethers,[*] hydrocarbons;[*] possible: amines,[*] alcohols/phenols | Possible: organosilicon compounds | Possible: esters,[*] ketones[*] |
| RAC-4, Tenax | Hydrocarbons,[*] esters,[*] ketones;[*] possible: alcohols/phenols, amines,[*] amides | | Possible: ethers[*] | |
| RAC 1-5, Particulate | | Esters,[*] ketones[*] saturated hydrocarbons; possible: ethers,[*] organosilicon compounds, substituted aromatics | | |

[*] May be saturated, unsaturated, aryl.

TABLE 16. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF XAD-2 RESIN EXTRACT AND ITS LC FRACTIONS, SASS RUN No. 2

| Sample code | Major | Medium | Minor | Trace | Weight distribution (percent) |
|---|---|---|---|---|---|
| XAD-2 resin[*] | | Aryl or unsaturated esters; ketones,[†] hydrocarbons | Possible: nitrocompounds, ethers | | 100[‡] |
| LC-1 | | Aliphatic hydrocarbons | Aromatic hydrocarbons | Esters (aryl or unsaturated); possible; ethers | 6.2 |
| LC-2 | | | | Hydrocarbons;[†] possible: saturated ethers | 0.4 |
| LC-3 | | | Esters[†] | Possible: saturated hydrocarbons, ethers | 3.8 |
| LC-4[§] | | | | | 20.8 |
| LC-5[§] | | | | | 6.7 |
| LC-6 | Esters,[†] ketones[†] | Possible: amines,[†] alcohols/phenols,[†] ethers,[†] nitrocompounds,[†] amines[†] | | | 54.9 |
| LC-7 | | Unsaturated esters; saturated and unsaturated ketones | Possible: ethers, nitrocompounds | | 7.3 |

[*] The spectra of some fractions are stronger than the spectrum of the unfractionated sample. Therefore, some compounds may show up in the spectrum of a fraction, but not in the spectrum of the unfractionated sample.

[†] May be saturated, unsaturated, and/or aryl.

[‡] Column percent recovery: 91 percent.

[§] Blank removes IR spectra.

TABLE 17. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF MODULE RINSE AND ITS LC FRACTIONS, SASS RUN No. 2

| Sample code | Major | Medium | Minor | Trace | Weight distribution (percent) |
|---|---|---|---|---|---|
| 2-MR | | | Aliphatic hydrocarbons esters (saturated, unsaturated, aryl); possible: aromatic hydrocarbons | Saturated ketones; possible: ethers | 100[†] |
| LC-1 | | | | Aliphatic hydrocarbons | 46.9 |
| LC-2[*] | | | | | 13.5 |
| LC-3[*] | | | | | 5.1 |
| LC-4 | | Esters (saturated) | Esters (unsaturated, aryl) | Possible: ethers | 16.4 |
| LC-5 | | | Esters (saturated) | Esters (unsaturated, aryl) | 1.6 |
| LC-6 | | | Esters (saturated) | Esters (unsaturated, aryl) | 14.4 |
| LC-7 | | | | Ethers (saturated) | 3.0 |

[*] Blank removes IR spectrum.

[†] Column percent recovery: 51 percent.

TABLE 18. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF TENAX RESIN EXTRACT AND ITS LC FRACTIONS, RAC RUN No. 4

| Sample code | Major | Medium | Minor | Trace | Weight distribution (percent) |
|---|---|---|---|---|---|
| RAC, Tenax | Hydrocarbons,[*] esters,[*] ketones;[*] possible: alcohols/phenols, amines,[*] amides,[*] ethers[*] | | | | 100[†] |
| LC-1 | | Saturated hydrocarbons | Aromatic hydrocarbons | Aryl or vinyl ethers | 8.8 |
| LC-2 | | Saturated hydrocarbons | | Unsaturated hydrocarbons | 0.2 |
| LC-3 | | Substituted aromatics, esters;[*] possible: amines,[*] amides,[*] ethers,[*] unsaturated alcohols | Possible: nitro-substituted compounds, phenols | | 11.4 |
| LC-4 | | Esters;[*] possible: amides,[*] amines,[*] ethers[*] | Possible: unsaturated alcohols, nitrosubstituted compounds | | 21.6 |
| LC-5 | | Esters,[*] ketones;[*] possible: amides,[*],[‡] amines,[*],[†] ethers,[*],[†] alcohols/phenols[†] | | | 36.6 |
| LC-6 | | Esters,[*] ketones;[*] possible: amides,[*],[†] amines,[*],[†] ethers,[*],[†] alcohols/phenols[†] | | | 18.3 |
| LC-7 | | | Ketones,[*] esters;[*] possible: ethers,[*] phenols, amines,[*],[‡] | | 3.0 |

[*] May be saturated, unsaturated, and/or aryl.

[†] Column percent recovery: 114 percent.

[‡] May possess an isopropyl group attached to N or O.

These data indicate that XAD-2 used in the SASS train and Tenax used in a modified RAC train produce qualitatively similar results. Differences in operating conditions over the several days of testing preclude quantitative comparison of the organic emissions data. In Section 5 the organic emissions data from the CAFB are compared with emissions from conventional lignite-fired boilers and with CAFB emissions during oil-firing.

Table 19 summarizes the organic composition of spent stone withdrawn from the regenerator. Over 99 percent of extractable material is nonvolatile. The esters and ethers contained in the material reflect the highly oxidizing nature of the regenerator. It is not unreasonable to assume that high molecular weight tars also remain on the stone; however, these compounds are probably insoluble in methylene chloride and, hence, undetectable in the Level I scheme.

TABLE 19. ORGANIC COMPOSITION OF SPENT STONE (mg/kg)

| TCO* | Gravimetric† | Total |
|---|---|---|
| 0.80 | 195 | 196 |

*Individual Alkane Equivalents:
$C_{14}$ = 0.60 $C_{16}$ = 0.2

†Infrared analysis shows minor amounts of aryl and unsaturated esters and ethers.

Inorganic and Trace Element Results--

The inorganic analysis program centered upon Spark Source Mass Spectrographic (SSMS) analysis of stack particulate, bed material, internal solids and vapor species collected on resin and in solution. Appendix D contains tabulations of the elemental compositions of each sample analyzed. In addition to SSMS, wet chemical methods and X-ray photoelectron spectroscopy (ESCA) were used to determine mercury, sulfate, fluoride, chloride and particulate surface species. The elemental compositions of lignite and limestone feeds are reported in Tables 20 and 21. Elements present in appreciable concentrations in one feed are also present in the other, thus no indicator elements are apparent.

Tables 22 and 23 contain trace element amounts and emission factors, determined by SSMS, for all SASS fractions for runs 1 and 2. The emission factors listed in the last column of each table are compared with MATE values and with emissions from conventional lignite-fired sources in Section 5. The milligram quantities tabulated under each sample designation refer to the total number of milligrams of each element determined to be in each sample. Ranges of values reported under "Total SASS" have as minima the sum of all real

TABLE 20. SSMS ANALYSIS OF CAFB LIGNITE*

| Element | Value (ppm) | Element | Value (ppm) | Element | Value (ppm) |
|---|---|---|---|---|---|
| U | 1.2 | Pr | 1.4 | Ge | < 3.0 |
| Th | 3.8 | Ce | 3.4 | Ga | 14 |
| Bi | < 0.33 | La | 10 | Zn | 11 |
| Pb | 13 | Ba | 320 | Cu | 19 |
| Tl | < 0.47 | Cs | 0.86 | Ni | 10 |
| Au | < 0.23 | I | 0.16 | Co | 2.2 |
| Pt | < 0.64 | Te | 4.9 | Fe | 0.57% |
| Ir | < 0.35 | Sb | 0.38 | Mn | 100 |
| Os | < 0.40 | Sn | 1.9 | Cr | 13 |
| Re | < 0.25 | In | IS† | V | 28 |
| W | < 0.60 | Cd | 0.69 | Ti | 0.14% |
| Hf | < 0.75 | Pd | < 0.18 | Ca | MC‡ |
| Lu | < 0.17 | Rh | < 0.064 | K | 0.49% |
| Yb | < 0.27 | Ru | < 0.23 | S | 0.86% |
| Tm | < 0.16 | Mo | 0.73 | P | 76 |
| Er | < 0.25 | Nb | 6.9 | Si | MC |
| Ho | < 0.15 | Zr | 65 | Al | MC |
| Dy | < 0.26 | Y | 8.2 | Mg | 0.44% |
| Tb | < 0.16 | Sr | 230 | Na | 80 |
| Gd | < 0.43 | Rb | 7.8 | F | 92 |
| Eu | < 0.12 | Br | 11 | B | 88 |
| Sm | < 0.73 | Se | < 9.3 | Be | 0.55 |
| Nd | 1.1 | As | < 57 | | |

*Concentrations based on "as received" lignite weight.

†IS - Internal Standard.

‡MC - Major Component.

## TABLE 21. SSMS ANALYSIS OF CAFB LIMESTONE FEED

| Element | Value (ppm) | Element | Value (ppm) | Element | Value (ppm) |
|---|---|---|---|---|---|
| U | < 0.63 | Pr | 0.21 | Ga | < 0.07 |
| Th | < 0.63 | Ce | 0.43 | Zn | < 1.4 |
| Bi | < 0.28 | La | 0.95 | Cu | 3.8 |
| Pb | 8.3 | Ba | 160 | Ni | 4.4 |
| Tl | < 0.33 | Cs | 0.06 | Co | 0.23 |
| Au | < 0.43 | I | 19 | Fe | 590 |
| Pt | < 1.2 | Te | < 0.35 | Mn | 7.5 |
| Ir | < 0.65 | Sb | 0.95 | Cr | 0.63 |
| Os | < 0.74 | Sn | 5.5 | V | 3.6 |
| Re | < 0.46 | In | IS[*] | Ti | 40 |
| W | < 0.61 | Pd | < 0.34 | Ca | MC[†] |
| Hf | < 0.75 | Rh | < 0.12 | K | 230 |
| Lu | < 0.17 | Ru | < 0.43 | S | 400 |
| Yb | < 0.27 | Mo | 0.87 | P | 27 |
| Tm | < 0.16 | Nb | < 0.05 | Si | 400 |
| Er | < 0.46 | Zr | 0.55 | Al | 150 |
| Ho | < 0.15 | Y | 0.24 | Mg | 0.36% |
| Dy | < 0.26 | Sr | 210 | Na | 110 |
| Tb | < 0.07 | Rb | 1.7 | F | 150 |
| Gd | < 0.28 | Br | < 21 | B | 5.5 |
| Eu | < 0.12 | Se | < 4.4 | Be | 0.003 |
| Sm | < 0.48 | As | < 328 | Li | 0.09 |
| Nd | < 0.50 | Ge | < 0.17 | | |

[*] IS - Internal Standard.

[†] MC - Major Component.

# TABLE 22. TRACE ELEMENT EMISSIONS IN SASS SAMPLES, RUN No. 1

CARB #1:   VOLUME SAMPLED = 26.03 DSCM

| ELEMENT | 10U CYCLONE (UG) | 3U CYCLONE (UG) | 1U CYCLONE (UG) | FILTER CATCH (UG) | XAD RESIN (UG) | COMPOSITE SAMPLE (UG) | TOTAL SASS (UG) | EMISSION FOUND (UG/DSCM) |
|---|---|---|---|---|---|---|---|---|
| U | 0.065 | 0.28 | 0.087 | 0.0085 | < 0.018 | < 0.013 | 0.44 | 0.017 |
| TH | 0.18 | 0.57 | 0.35 | 0.012 | < 0.026 | < 0.020 | 1.1 | 0.043 |
| BI | < 0.056 | < 0.48 | < 0.30 | 0.014 | < 0.0061 | < 0.0061 | 0.014 TO 0.85 | 0.0005 TO 0.033 |
| PB | 0.77 | 1.4 | 2.5 | 0.12 | < 0.28 | < 0.070 | 4.8 | 0.18 |
| TL | < 0.0096 | < 0.0066 | < 0.011 | < 0.0040 | < 0.0100 | < 0.0076 | < 0.051 | < 0.0020 |
| AU | < 0.0025 | < 0.011 | < 0.013 | < 0.0002 | < 0.014 | < 0.0100 | < 0.050 | < 0.0019 |
| IR | < 0.0038 | < 0.016 | < 0.020 | < 0.0003 | < 0.021 | < 0.016 | < 0.077 | < 0.0030 |
| OS | < 0.0041 | < 0.018 | < 0.022 | < 0.0003 | < 0.023 | < 0.017 | < 0.084 | < 0.0032 |
| RE | < 0.0026 | < 0.011 | < 0.014 | < 0.0002 | < 0.014 | < 0.011 | < 0.053 | < 0.0020 |
| W | < 0.014 | < 0.042 | < 0.052 | < 0.0032 | < 0.019 | < 0.014 | < 0.15 | < 0.0056 |
| HF | < 0.062 | < 0.13 | < 0.33 | < 0.0034 | < 0.024 | < 0.018 | < 0.57 | < 0.022 |
| LU | < 0.025 | < 0.052 | < 0.063 | < 0.0003 | < 0.0056 | < 0.0042 | < 0.15 | < 0.0058 |
| YB | < 0.019 | < 0.055 | < 0.051 | < 0.0021 | < 0.0082 | < 0.0061 | < 0.14 | < 0.0055 |
| TM | < 0.0075 | < 0.0039 | < 0.0048 | < 0.0006 | < 0.0050 | < 0.0037 | < 0.026 | < 0.0010 |
| ER | < 0.027 | < 0.012 | < 0.099 | < 0.0021 | < 0.015 | < 0.011 | < 0.17 | < 0.0064 |
| HO | < 0.0051 | < 0.022 | < 0.019 | 0.0006 | < 0.0048 | < 0.0036 | 0.0006 TO 0.055 | < 0.0001 TO 0.0021 |
| DY | < 0.072 | < 0.0066 | < 0.13 | 0.0041 | < 0.0084 | < 0.0062 | 0.0041 TO 0.23 | 0.0002 TO 0.0087 |
| TB | < 0.0003 | < 0.0013 | < 0.0016 | < 0.0001 | < 0.0023 | < 0.0017 | < 0.0072 | < 0.0003 |
| GD | < 0.036 | < 0.0066 | < 0.051 | < 0.0027 | < 0.0083 | < 0.0062 | < 0.11 | < 0.0042 |
| EU | 0.013 | < 0.041 | < 0.034 | 0.0010 | < 0.0038 | < 0.0028 | 0.014 TO 0.082 | 0.0005 TO 0.0031 |
| SM | 0.075 | < 0.16 | < 0.20 | 0.0048 | < 0.015 | < 0.011 | 0.080 TO 0.39 | 0.0031 TO 0.015 |
| ND | 0.17 | 0.36 | 0.22 | 0.013 | < 0.018 | < 0.014 | 0.76 | 0.029 |
| PR | 0.051 | 0.12 | 0.073 | 0.0040 | < 0.0032 | < 0.0024 | 0.25 | 0.0095 |
| CE | 0.40 | 0.85 | 1.1 | 0.060 | < 0.0043 | < 0.0032 | 2.4 | 0.091 |
| LA | 0.56 | 1.2 | 3.0 | 0.033 | < 0.0047 | < 0.0035 | 4.8 | 0.18 |
| BA | 8.5 | 21. | 39. | 0.35 | < 0.076 | 0.013 | 69. | 2.6 |
| CS | 0.024 | 0.038 | 0.024 | 0.0031 | < 0.0008 | < 0.0006 | 0.090 | 0.0034 |
| I | 0.032 | < 0.025 | < 0.0075 | < 0.0002 | < 0.013 | < 0.0093 | 0.032 | 0.0012 |
| TE | < 0.039 | < 0.048 | < 0.100 | < 0.0053 | < 0.011 | < 0.0076 | < 0.21 | < 0.0081 |
| SB | 0.022 | 0.067 | 0.079 | 0.0050 | < 0.0073 | < 0.0054 | 0.17 | 0.0067 |
| SN | 0.072 | 0.15 | 0.13 | < 0.025 | 0.039 | 1.3 | 1.7 | 0.066 |
| CD | 0.019 | 0.028 | 0.027 | 0.027 | < 0.013 | 0.029 | 0.13 | 0.0050 |
| PD | < 0.042 | < 0.091 | < 0.036 | < 0.0018 | < 0.0100 | < 0.0078 | < 0.19 | < 0.0074 |
| RH | < 0.0078 | < 0.0029 | < 0.0035 | < 0.0012 | < 0.0037 | < 0.0027 | < 0.022 | < 0.0008 |

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# TABLE 22 (continued)

CARB #1: VOLUME SAMPLED = 26.03 DSCM

| ELEMENT | 100M CYCLONE (MG) | 30M CYCLONE (MG) | 10M CYCLONE (MG) | FILTER CATCH (MG) | XAD RESIN (MG) | COMPOSITE SAMPLE (MG) | TOTAL SASS (MG) | EMISSION FOUND (MG/DSCM) |
|---|---|---|---|---|---|---|---|---|
| RU | < 0.0021 | < 0.0089 | < 0.011 | < 0.0002 | < 0.013 | < 0.0100 | < 0.046 | < 0.0018 |
| MO | 0.030 | 0.080 | 0.079 | 0.012 | < 0.012 | < 0.0093 | 0.20 | 0.0077 |
| NB | 0.33 | 0.72 | 0.89 | 0.0026 | < 0.0016 | < 0.0012 | 1.9 | 0.075 |
| ZR | 1.9 | 5.4 | 5.0 | 0.062 | < 0.0059 | < 0.0044 | 12. | 0.47 |
| Y | 0.67 | 1.0 | 1.3 | 0.012 | < 0.0024 | < 0.0018 | 3.0 | 0.12 |
| SR | 11. | 30. | 20. | 0.53 | < 0.21 | 0.0079 | 62. | 2.4 |
| RB | 0.23 | 0.56 | 0.44 | 0.015 | < 0.0061 | < 0.0031 | 1.2 | 0.046 |
| BR | 1.0 | 1.6 | 1.4 | < 0.025 | < 0.87 | < 0.075 | 4.0 | 0.15 |
| SE | < 0.67 | < 0.39 | < 0.68 | < 0.020 | < 0.060 | 0.013 | 0.013 TO 1.8 | 0.0005 TO 0.070 |
| AS | 2.4 | 5.9 | 7.3 | 0.065 | 0.0056 | < 0.012 | 16. | 0.60 |
| GE | 0.15 | < 0.47 | < 0.30 | < 0.0066 | < 0.0050 | < 0.0037 | 0.15 TO 0.79 | 0.0056 TO 0.030 |
| GA | 0.39 | 1.7 | 1.9 | 0.100 | < 0.0021 | < 0.0015 | 4.1 | 0.16 |
| ZN | 8.2 | 6.8 | 5.3 | < 0.66 | < 1.6 | 0.45 | 21. | 0.80 |
| CU | 1.2 | 0.93 | 1.6 | < 0.25 | < 2.5 | 0.60 | 4.3 | 0.17 |
| NI | 0.57 | 2.4 | 2.1 | < 0.13 | < 1.5 | 0.35 | 5.5 | 0.21 |
| CO | 0.26 | 0.40 | 0.49 | 0.012 | < 0.047 | < 0.025 | 1.2 | 0.045 |
| FE | MC | 480. | 350. | 5.4 | 1.7 | 3.8 | - | - |
| MN | 24. | 10. | 7.0 | 0.25 | < 0.15 | 0.15 | 41. | 1.6 |
| CR | 0.50 | 0.73 | 1.0 | 0.15 | < 0.090 | 0.32 | 2.7 | 0.100 |
| V | 1.1 | 2.8 | 3.4 | 0.083 | < 0.020 | 0.0077 | 7.4 | 0.28 |
| TI | 79. | 100. | 130. | 1.8 | < 0.067 | < 0.035 | 310. | 12. |
| CA | 810. | ** | ** | 44. | < 9.2 | 170. | ** | 190. |
| K | 21. | 140. | 99. | 4.4 | < 4.8 | < 0.68 | 260. | 10. |
| S | MC | 260. | 450. | 17. | <120. | 120. | - | - |
| P | 2.7 | 21. | 14. | 0.34 | < 1.6 | < 4.0 | 38. | 1.5 |
| SI | 830. | ** | 790. | < 5.0 | < 14. | 0.38 | ** | 210. |
| AL | MC | 560. | 290. | 14. | < 2.0 | 0.23 | - | - |
| MG | 59. | 210. | 94. | 8.8 | < 6.2 | 0.26 | 300. | 14. |
| NA | 11. | 89. | 25. | MC | < 25. | < 3.4 | - | - |
| B | 4.2 | 31. | 69. | < 0.60 | 0.11 | 0.11 | 100. | 4.0 |
| BE | 0.044 | 0.068 | 0.24 | 0.0010 | < 0.0012 | 0.0001 | 0.35 | 0.013 |

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

## TABLE 23. TRACE ELEMENT EMISSIONS IN SASS SAMPLES, RUN No. 2

CAPS #2: VOLUME SAMPLED = 7.541 DSCM

| ELEMENT | 100M CYCLONE (MG) | 3UM CYCLONE (MG) | 1UM CYCLONE (MG) | FILTER CATCH (MG) | XAD RESIN (MG) | COMPOSITE SAMPLE (MG) | TOTAL SASS (MG) | EMISSION FOUND (MG/DSCM) |
|---|---|---|---|---|---|---|---|---|
| U | 0.024 | 0.050 | 0.018 | 0.0023 | < 0.100 | < 0.022 | 0.100 | 0.013 |
| TH | 0.081 | 0.14 | 0.035 | 0.0033 | < 0.15 | < 0.031 | 0.26 | 0.035 |
| BI | < 0.035 | < 0.12 | < 0.0026 | 0.0039 | < 0.046 | < 0.0097 | 0.0039 TO 0.21 | 0.0005 TO 0.028 |
| PB | 0.21 | 1.0 | 1.0 | 0.046 | < 0.27 | < 0.020 | 2.3 | 0.31 |
| TL | < 0.0014 | < 0.0018 | < 0.022 | < 0.0015 | < 0.057 | < 0.012 | < 0.096 | < 0.013 |
| AU | < 0.0022 | < 0.0019 | < 0.0009 | < 0.0001 | < 0.076 | < 0.016 | < 0.098 | < 0.013 |
| IR | < 0.0034 | < 0.0029 | < 0.0015 | < 0.0002 | < 0.12 | < 0.025 | < 0.15 | < 0.020 |
| OS | < 0.0037 | < 0.0032 | < 0.0016 | < 0.0002 | < 0.13 | < 0.027 | < 0.16 | < 0.022 |
| RE | < 0.0023 | < 0.0020 | < 0.0010 | < 0.0010 | < 0.081 | < 0.017 | < 0.100 | < 0.014 |
| W | < 0.0087 | < 0.022 | < 0.0079 | < 0.0012 | < 0.11 | < 0.023 | < 0.17 | < 0.023 |
| HF | < 0.11 | < 0.071 | < 0.024 | < 0.0013 | < 0.14 | < 0.029 | < 0.37 | < 0.049 |
| LU | < 0.031 | < 0.027 | < 0.0046 | < 0.0001 | < 0.032 | < 0.0067 | < 0.100 | < 0.013 |
| YB | < 0.011 | < 0.020 | < 0.0053 | < 0.0007 | < 0.046 | < 0.0097 | < 0.094 | < 0.012 |
| TM | < 0.0045 | < 0.0007 | < 0.0041 | < 0.0002 | < 0.028 | < 0.0060 | < 0.044 | < 0.0058 |
| ER | < 0.016 | < 0.014 | < 0.0072 | < 0.0009 | < 0.083 | < 0.018 | < 0.14 | < 0.018 |
| HO | < 0.0032 | < 0.0079 | < 0.0020 | < 0.0006 | < 0.027 | < 0.0057 | < 0.047 | < 0.0062 |
| DY | < 0.022 | < 0.039 | < 0.020 | < 0.0067 | < 0.047 | < 0.0100 | < 0.15 | < 0.019 |
| TB | < 0.0003 | < 0.0002 | < 0.0001 | < 0.0003 | < 0.013 | < 0.0027 | < 0.016 | < 0.0022 |
| GD | < 0.016 | < 0.023 | < 0.0068 | < 0.0012 | < 0.047 | < 0.0099 | < 0.100 | < 0.014 |
| EU | < 0.011 | < 0.021 | < 0.0037 | 0.0002 | < 0.021 | < 0.0045 | 0.0002 TO 0.061 | < 0.0001 TO 0.0081 |
| SM | < 0.055 | < 0.082 | 0.0072 | 0.0013 | < 0.082 | < 0.017 | 0.0085 TO 0.24 | 0.0011 TO 0.031 |
| ND | < 0.20 | 0.089 | 0.032 | 0.0078 | < 0.100 | < 0.022 | 0.13 TO 0.33 | 0.017 TO 0.044 |
| PR | 0.024 | 0.029 | 0.028 | 0.0011 | < 0.018 | < 0.0038 | 0.082 | 0.011 |
| CE | 0.35 | 0.15 | 0.21 | 0.016 | < 0.025 | < 0.0052 | 0.73 | 0.097 |
| LA | 0.35 | 0.86 | 0.31 | 0.0089 | < 0.027 | < 0.0056 | 1.5 | 0.20 |
| BA | 6.5 | 21. | 11. | < 0.69 | 0.051 | 0.011 | 38. | 5.1 |
| CS | 0.0078 | 0.0093 | 0.0093 | < 0.0020 | < 0.0043 | < 0.0009 | 0.026 | 0.0035 |
| I | 0.021 | < 0.0032 | < 0.0023 | < 0.0002 | < 0.071 | < 0.015 | 0.021 TO 0.091 | 0.0027 TO 0.012 |
| TE | < 0.017 | < 0.018 | < 0.0090 | 0.0010 | < 0.059 | < 0.013 | 0.0010 TO 0.12 | 0.0001 TO 0.015 |
| SB | 0.037 | 0.032 | 0.061 | 0.0052 | < 0.041 | < 0.0087 | 0.14 | 0.018 |
| SN | 0.035 | 0.043 | 0.060 | < 0.037 | < 0.058 | < 2.9 | 0.14 TO 3.0 | 0.018 TO 0.40 |
| CD | 0.0038 | 0.0070 | 0.0044 | < 0.017 | < 0.073 | < 0.12 | 0.015 TO 0.21 | 0.0020 TO 0.028 |
| PD | < 0.019 | < 0.016 | < 0.012 | < 0.0007 | < 0.059 | < 0.012 | < 0.12 | < 0.016 |
| RH | < 0.0033 | < 0.0005 | < 0.0003 | < 0.0002 | < 0.021 | < 0.0044 | < 0.029 | < 0.0039 |

## TABLE 23 (continued)

CAFB #2:  VOLUME SAMPLED = 7.541 DSCM

| ELEMENT | 10UM CYCLONE (MG) | 3UM CYCLONE (MG) | 1UM CYCLONE (MG) | FILTER CATCH (MG) | XAD RESIN (MG) | COMPOSITE SAMPLE (MG) | TOTAL SASS (MG) | EMISSION FOUND (MG/DSCM) |
|---|---|---|---|---|---|---|---|---|
| RU | < 0.0018 | < 0.0016 | < 0.0008 | < 0.0015 | < 0.076 | < 0.016 | < 0.098 | < 0.013 |
| MO | 0.019 | 0.023 | 0.016 | 0.0063 | < 0.070 | 0.030 | 0.094 | 0.012 |
| NB | 0.15 | 0.15 | 0.26 | 0.0014 | < 0.0088 | 0.0026 | 0.59 | 0.079 |
| ZR | 1.0 | 1.8 | 1.3 | 0.011 | < 0.033 | < 0.0070 | 4.1 | 0.54 |
| Y | 0.21 | 0.19 | 0.26 | 0.0045 | < 0.014 | < 0.0029 | 0.66 | 0.088 |
| SR | 20. | 9.9 | 7.2 | 0.43 | < 0.28 | 0.0050 | 38. | 5.0 |
| RB | 0.21 | 0.18 | 0.090 | < 0.011 | < 0.048 | 0.0009 | 0.48 | 0.063 |
| BR | 0.65 | 0.57 | 0.19 | < 0.0091 | < 1.7 | < 0.062 | 1.4 | 0.19 |
| SE | < 0.42 | < 0.52 | < 0.26 | 0.029 | < 0.040 | 0.077 | 0.11 TO 1.2 | 0.014 TO 0.16 |
| AS | 3.6 | 1.1 | 2.9 | 0.024 | < 0.016 | 0.0033 | 7.6 | 1.0 |
| GE | < 0.13 | 0.081 | 0.23 | 0.0009 | < 0.028 | < 0.0060 | 0.31 | 0.041 |
| GA | 0.34 | 0.60 | 0.97 | 0.064 | < 0.012 | < 0.0024 | 2.0 | 0.26 |
| ZN | 11. | 1.7 | 1.2 | < 0.27 | < 2.0 | < 0.47 | 14. | 1.9 |
| CU | 0.53 | 0.66 | 0.46 | < 0.18 | < 2.6 | 0.28 | 1.9 | 0.26 |
| NI | 0.25 | 0.44 | 0.32 | < 0.033 | < 4.3 | < 0.48 | 1.0 TO 4.8 | 0.13 TO 0.64 |
| CO | 0.082 | 0.14 | 0.100 | < 0.0038 | < 0.032 | 0.0070 | 0.33 | 0.044 |
| FE | MC | 160. | 140. | 1.1 | < 6.5 | < 1.9 | * | * |
| MN | 12. | 1.8 | 1.7 | 0.055 | < 0.22 | < 0.095 | 15. | 2.0 |
| CR | 0.24 | 0.13 | 1.9 | 0.052 | < 0.11 | 0.14 | 2.5 | 0.33 |
| V | 1.0 | 0.87 | 1.3 | 0.014 | < 0.014 | < 0.0057 | 3.2 | 0.43 |
| TI | 38. | 33. | 31. | 0.55 | < 0.19 | < 0.098 | 100. | 14. |
| CA | 240. | 820. | MC | 24. | < 17. | < 2.2 | * | * |
| K | 22. | 25. | 12. | < 0.92 | < 10. | < 0.76 | 58. | 7.7 |
| S | 690. | 200. | 55. | 8.5 | 560. | 160. | ** | 220. |
| P | 4.3 | 2.1 | 5.6 | 0.074 | < 4.5 | < 6.4 | 12. | 1.6 |
| SI | MC | 400. | 320. | < 1.7 | < 9.9 | < 1.5 | * | * |
| AL | MC | 120. | MC | 11. | < 3.9 | < 0.58 | * | * |
| MG | 46. | 21. | 46. | 1.4 | < 6.2 | < 0.70 | 110. | 15. |
| NA | 14. | 9.9 | 14. | < 26. | < 76. | < 5.4 | 38. TO 110. | 5.0 TO 14. |
| B | 11. | 5.5 | 5.0 | < 0.18 | 0.40 | 0.97 | 23. | 3.1 |
| BE | 0.0070 | 0.0085 | 0.012 | < 0.0004 | 0.0012 | < 0.0001 | 0.029 | 0.0038 |
| LI | 0.25 | 0.12 | 0.062 | < 0.0037 | 0.018 | < 0.014 | 0.46 | 0.060 |

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

* INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

quantities. Upper limits are sums of real values and "less thans." Quantities reported as "less than" mean that either an element was not present at values above its detection limit (in which case the detection limit is the "less than" value employed) or that the elemental value did not exceed its value in the appropriate blank (in which case the blank value is the "less than"). "Major component" is used for concentrations exceeding a few percent.

The bulk of the trace elements are found in the stack particulate, with only a few elements present at greater than their blank values after the filter. The composite sample is a combination of the first impinger, a nitric acid module rinse and the module condensate.

Tables 24 and 25 list trace element totals and emission factors determined from cyclone and filter catches from RAC runs 1 and 2. Although neither Tenax nor impingers were analyzed for trace elements, the distribution found in SASS samples (see Tables 22 and 23) indicates that most trace elements are found in the particulate catches. In general, the emission factors from the RAC and SASS samples agree within the factor of 3 noted earlier, although the RAC values are consistently lower. There is no evidence for contamination of SASS collected samples by iron, chromium or manganese from the stainless steel probe or cyclones. One major difference between the SASS and RAC emission factors is arsenic, with the RAC values for this element lower by a factor of 20 to 40. The higher oven temperature of the SASS would suggest that the volatile element arsenic would be more readily collected on RAC particulates; however, the opposite is true.

Analysis of SASS train samples for mercury, fluoride, chloride, and sulfate resulted in the sample concentrations displayed in Table 26. As with the SSMS data, these results show that most of the inorganic substances are in the particulate rather than the gaseous portions of the CAFB emissions even for the volatile element mercury.

Mercury emission rates for SASS runs 1 and 2 are 2.02 $\mu g/m^3$ and 4.00 $\mu g/m^3$ which represent 10.5 percent and 24.1 percent, respectively, of the mercury in the lignite. Fluoride emission rates are 1.01 $mg/m^3$ and 2.35 $mg/m^3$ corresponding to 9.2 percent and 24.8 percent, respectively, of the fluoride in the lignite. Chloride emission rates are 0.53 $mg/m^3$ and 3.25 $mg/m^3$ which correspond to 0.2 percent and 1.8 percent, respectively, of the chloride in the lignite.

A combination of laboratory and field data ($SO_2$-$SO_3$ emissions) is necessary for a complete evaluation of sulfur emissions. Such a combination shows:

- The $SO_x$ emissions measured corresponding to the SASS-1 run are $SO_2$, 101.9 ppmv, or 407.3 $mg/m^3$ sulfate, and $SO_3$, 0.8 ppmv, or 3.1 $mg/m^3$ sulfate. Combined with the SASS-1 measurements, these total 470 $mg/m^3$ or 21.5 percent of the total sulfur in the lignite.

- The $SO_x$ emissions corresponding to SASS-2 were $SO_2$, 299.7 ppmv, or 1197.9 $mg/m^3$ of sulfate, and $SO_3$, 1.3 ppmv, or 5.1 $mg/m^3$ of

# TABLE 24. RAC-1 TRACE ELEMENT EMISSIONS

| ELEMENT | CYCLONE CATCH (MG) | FILTER CATCH (MG) | TOTAL RAC (MG) | EMISSION FOUND (MG/DSCM) |
|---|---|---|---|---|
| U | 0.0032 | < 0.0088 | 0.0032 TO 0.0088 | 0.0038 TO 0.011 |
| TH | 0.0063 | < 0.018 | 0.0063 TO 0.018 | 0.0075 TO 0.021 |
| BI | 0.0005 | < 0.0053 | 0.0005 TO 0.0053 | 0.0006 TO 0.0063 |
| PB | 0.017 | 0.040 | 0.056 | 0.067 |
| TL | 0.0065 | < 0.0003 | 0.0065 | 0.0078 |
| AU | < 0.0002 | < 0.0003 | < 0.0005 | < 0.0006 |
| IR | < 0.0003 | < 0.0005 | < 0.0008 | < 0.0009 |
| OS | < 0.0003 | < 0.0006 | < 0.0008 | < 0.0010 |
| RE | 0.0005 | < 0.0029 | 0.0005 TO 0.0029 | 0.0006 TO 0.0035 |
| W | 0.0002 | < 0.0028 | 0.0002 TO 0.0028 | 0.0003 TO 0.0033 |
| HF | < 0.0030 | < 0.0060 | < 0.0090 | < 0.011 |
| LU | < 0.0008 | < 0.0034 | < 0.0042 | < 0.0050 |
| YB | < 0.0013 | < 0.0017 | < 0.0029 | < 0.0035 |
| TM | < 0.0005 | < 0.0007 | < 0.0012 | < 0.0014 |
| ER | < 0.0013 | < 0.0030 | < 0.0042 | < 0.0051 |
| HO | < 0.0001 | < 0.0010 | < 0.0011 | < 0.0013 |
| DY | < 0.0009 | < 0.0078 | < 0.0087 | < 0.0100 |
| TB | < 0.0002 | < 0.0001 | < 0.0003 | < 0.0003 |
| GD | < 0.0006 | < 0.0020 | < 0.0026 | < 0.0031 |
| EU | < 0.0006 | < 0.0036 | < 0.0043 | < 0.0051 |
| SM | 0.0013 | 0.0036 | 0.0049 | 0.0058 |
| ND | 0.0028 | 0.012 | 0.014 | 0.017 |
| PR | 0.0009 | 0.0051 | 0.0060 | 0.0071 |
| CE | 0.0095 | 0.027 | 0.036 | 0.043 |
| LA | 0.013 | 0.038 | 0.051 | 0.061 |
| BA | 0.19 | 0.71 | 0.89 | 1.1 |
| CS | 0.0003 | 0.0012 | 0.0015 | 0.0018 |
| I | 0.0016 | < 0.0011 | 0.0016 | 0.0019 |
| TE | < 0.0013 | < 0.0025 | < 0.0038 | < 0.0046 |
| SB | 0.0007 | 0.0015 | 0.0022 | 0.0027 |
| SN | 0.0012 | 0.0068 | 0.0080 | 0.0095 |
| CD | 0.0002 | 0.0008 | 0.0011 | 0.0013 |
| PD | < 0.0014 | < 0.0019 | < 0.0034 | < 0.0040 |
| RH | < 0.0002 | < 0.0001 | < 0.0003 | < 0.0003 |
| RU | < 0.0001 | < 0.0003 | < 0.0004 | < 0.0005 |
| MO | 0.0009 | 0.0018 | 0.0027 | 0.0032 |
| NB | 0.0057 | 0.016 | 0.022 | 0.026 |
| ZR | 0.065 | 0.22 | 0.29 | 0.34 |
| Y | 0.012 | 0.016 | 0.028 | 0.033 |
| SR | 0.44 | 0.61 | 1.0 | 1.2 |
| RB | 0.0057 | 0.016 | 0.022 | 0.026 |
| BR | 0.012 | < 0.0093 | 0.012 | 0.015 |
| SE | 0.0044 | < 0.0086 | 0.0044 | 0.0052 |
| AS | 0.014 | 0.0070 | 0.021 | 0.025 |
| GE | < 0.0075 | < 0.0077 | < 0.015 | < 0.018 |
| GA | 0.012 | < 0.068 | 0.012 TO 0.068 | 0.015 TO 0.081 |
| ZN | 0.56 | 0.093 | 0.66 | 0.78 |
| CU | 0.020 | 0.040 | 0.061 | 0.072 |
| NI | 0.79 | 0.035 | 0.82 | 0.98 |
| CO | 0.0044 | 0.0043 | 0.0087 | 0.0100 |
| FE | 25. | 15. | 40. | 48. |
| MN | 0.53 | 0.18 | 0.71 | 0.84 |
| CR | 0.018 | 0.015 | 0.033 | 0.039 |
| V | 0.044 | 0.086 | 0.13 | 0.15 |
| TI | 1.6 | 11. | 12. | 15. |
| CA | 33. | 110. | 140. | 170. |
| K | 1.3 | 4.3 | 5.6 | 6.6 |
| S | 29. | 8.1 | 37. | 44. |
| P | 0.033 | 0.20 | 0.23 | 0.27 |
| SI | 15. | 90. | 100. | 120. |
| AL | 2.3 | MC | - | - |
| MG | 1.2 | 4.2 | 5.4 | 6.4 |
| NA | 0.100 | 1.2 | 1.3 | 1.5 |
| B | 0.15 | 0.96 | 1.1 | 1.3 |
| BE | 0.0004 | 0.0007 | 0.0011 | 0.0013 |
| LI | 0.0060 | 0.0065 | 0.013 | 0.015 |

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

# TABLE 25. RAC-2 TRACE ELEMENT EMISSIONS

| ELEMENT | CYCLONE CATCH (MG) | FILTER CATCH (MG) | TOTAL RAC (MG) | EMISSION FOUND (MG/DSCM) |
|---|---|---|---|---|
| U | 0.0026 | 0.0050 | 0.0076 | 0.0079 |
| TH | 0.0038 | 0.015 | 0.018 | 0.019 |
| BI | 0.0005 | 0.0046 | 0.0050 | 0.0052 |
| PB | 0.049 | 0.083 | 0.13 | 0.14 |
| TL | < 0.0006 | < 0.0033 | < 0.0039 | < 0.0041 |
| AU | < 0.0001 | < 0.0005 | < 0.0006 | < 0.0006 |
| IR | < 0.0002 | < 0.0007 | < 0.0009 | < 0.0009 |
| OS | < 0.0002 | < 0.0008 | < 0.0010 | < 0.0010 |
| RE | 0.0003 | < 0.0040 | 0.0003 TO 0.0040 | 0.0003 TO 0.0042 |
| W | 0.0004 | 0.0018 | 0.0022 | 0.0023 |
| HF | < 0.0003 | < 0.0008 | < 0.0011 | < 0.0011 |
| LU | < 0.0001 | < 0.0005 | < 0.0007 | < 0.0007 |
| YB | < 0.0006 | < 0.0030 | < 0.0036 | < 0.0038 |
| TM | < 0.0001 | < 0.0014 | < 0.0015 | < 0.0016 |
| ER | < 0.0007 | < 0.0051 | < 0.0057 | < 0.0060 |
| HO | < 0.0003 | < 0.0027 | < 0.0030 | < 0.0031 |
| DY | < 0.0006 | < 0.0011 | < 0.0018 | < 0.0018 |
| TB | 0.0001 | < 0.0026 | 0.0001 TO 0.0026 | 0.0001 TO 0.0027 |
| GD | < 0.0004 | < 0.0028 | < 0.0032 | < 0.0034 |
| EU | 0.0002 | 0.0008 | 0.0010 | 0.0010 |
| SM | 0.0009 | 0.0048 | 0.0057 | 0.0059 |
| ND | 0.0035 | 0.034 | 0.037 | 0.039 |
| PR | 0.0010 | 0.0069 | 0.0079 | 0.0082 |
| CE | 0.014 | 0.051 | 0.065 | 0.068 |
| LA | 0.0069 | 0.040 | 0.047 | 0.049 |
| BA | 0.24 | 1.5 | 1.8 | 1.8 |
| CS | 0.0004 | 0.0016 | 0.0021 | 0.0021 |
| I | 0.0020 | 0.0025 | 0.0044 | 0.0046 |
| TE | < 0.0005 | < 0.0045 | < 0.0049 | < 0.0051 |
| SB | 0.0011 | 0.011 | 0.012 | 0.013 |
| SN | 0.0014 | 0.016 | 0.017 | 0.018 |
| CD | 0.0008 | 0.0099 | 0.011 | 0.011 |
| PD | < 0.0001 | < 0.0020 | < 0.0021 | < 0.0022 |
| RH | < 0.0001 | < 0.0002 | < 0.0003 | < 0.0003 |
| RU | < 0.0001 | < 0.0004 | < 0.0006 | < 0.0006 |
| MO | 0.0008 | 0.0087 | 0.0095 | 0.0099 |
| NB | 0.0031 | 0.0092 | 0.012 | 0.013 |
| ZR | 0.036 | 0.14 | 0.17 | 0.18 |
| Y | < 0.0001 | 0.020 | 0.020 | 0.021 |
| SR | 0.19 | 2.0 | 2.2 | 2.2 |
| RB | 0.0036 | 0.024 | 0.028 | 0.029 |
| BR | 0.0079 | 0.0100 | 0.018 | 0.019 |
| SE | 0.0041 | 0.018 | 0.022 | 0.023 |
| AS | 0.0070 | 0.047 | 0.054 | 0.057 |
| GE | 0.011 | 0.013 | 0.024 | 0.025 |
| GA | 0.0092 | 0.12 | 0.13 | 0.14 |
| ZN | 0.36 | 0.16 | 0.52 | 0.54 |
| CU | 0.031 | 0.16 | 0.20 | 0.20 |
| NI | 0.0051 | 0.012 | 0.017 | 0.018 |
| CO | 0.0021 | 0.0083 | 0.0100 | 0.011 |
| FE | 9.0 | 12. | 21. | 21. |
| MN | 0.20 | 0.41 | 0.61 | 0.63 |
| CR | 0.0059 | 0.062 | 0.068 | 0.071 |
| V | 0.041 | 0.20 | 0.24 | 0.25 |
| TI | 0.45 | 7.9 | 8.3 | 8.7 |
| CA | 33. | 110. | 140. | 150. |
| K | 0.36 | 3.2 | 3.6 | 3.7 |
| S | 47. | 11. | 58. | 60. |
| P | 0.042 | 0.49 | 0.53 | 0.55 |
| SI | 6.9 | 67. | 74. | 77. |
| AL | 1.1 | 12. | 13. | 14. |
| MG | 0.54 | 28. | 28. | 29. |
| NA | 0.13 | 0.84 | 0.97 | 1.0 |
| B | 0.046 | 0.37 | 0.42 | 0.43 |
| BE | 0.0002 | 0.0012 | 0.0014 | 0.0015 |
| LI | 0.0024 | 0.027 | 0.029 | 0.031 |

TABLE 26. CONCENTRATIONS OF SELECTED INORGANIC SPECIES IN SASS SAMPLES FROM THE CAFB-LIGNITE PROCESS*

| Sample | Mercury (µg/g) | Sulfate (mg/g) | Fluoride (mg/g) | Chloride (mg/g) |
|---|---|---|---|---|
| SASS Run No. 1 | | | | |
| filter | 1.24 | 59 | 0.59 | ND |
| 1µ cyclone | 0.80 | 8.2 | 0.42 | 0.005 |
| 3µ cyclone | 0.70 | 7.4 | 0.09 | 0.10 |
| 10µ cyclone | 1.12 | 75 | 0.35 | - |
| XAD | < 0.072 | 1.8 | 0.02 | ND |
| CH† | 0.014 µg/mℓ | - | 0.05 mg/mℓ | 0.008 mg/mℓ |
| IC‡ | 0.003 µg/mℓ | - | - | - |
| SASS Run No. 2 | | | | |
| filter | 12.67 | 110 | 1.06 | ND |
| 1µ cyclone | 1.87 | 22 | 0.50 | 0.38 |
| 3µ cyclone | 1.19 | 21 | 0.23 | 0.38 |
| 10µ cyclone | 0.79 | 74 | 1.30 | 0.77 |
| XAD | < 0.081 | 0.32 | - | 0.14 |
| CH† | 0.034 µg/mℓ | - | - | 0.015 mg/mℓ |
| IC‡ | 0.003 µg/mℓ | - | - | - |

*All values blank corrected.

†Combination of first impinger, condensate, and acid module rinse.

‡Combination of second and third impingers.

ND = none detected; sample is less than or equal to blank.

sulfate. Added to the SASS train catch, this results in 1297 mg/m$^3$ sulfate or 68.6 percent of the sulfur in the lignite.

These sulfur balances point out the extremely poor sulfur removal efficiency of the gasifier bed during SASS No. 2 and the relatively better performance during SASS No. 1. These conclusions are consistent with the observations made concerning the organic emissions data that the CAFB was more "chemically active" during SASS No. 1 than during SASS No. 2.

Table 27 lists concentrations of mercury, sulfate, fluoride and chloride for various nonstack samples collected during SASS No. 2. In general, fly ash and bed material from the same unit operation (regenerator bed and cyclone; gasifier bed and main cyclone) have similar concentrations of these species indicating that fly ash is representative of the bed material. The mercury and sulfate concentrations in the stack cyclone and knockout baffle pass readily through the hot gasifier and boiler and condense in the cooler stack region.

TABLE 27. CONCENTRATIONS OF SELECTED INORGANIC SPECIES IN SOLID SAMPLES COLLECTED FOR THE CAFB-LIGNITE STUDY

| Sample | Mercury (µg/g) | Sulfate (mg/g) | Fluoride (mg/g) | Chloride (mg/g) |
|---|---|---|---|---|
| Gasifier bed | 0.037 | 1.2 | 0.08 | 2.0 |
| Main cyclone | 0.029 | 1.0 | 0.13 | 0.78 |
| Regenerator bed | 0.029 | 2.2 | 0.09 | 0.14 |
| Regenerator cyclone | 0.054 | 1.8 | 0.21 | 2.0 |
| Stack cyclone | 0.129 | 2.0 | 0.15 | 0.054 |
| Stack knockout baffle | 0.833 | 3.4 | 0.19 | 0.2 |
| Lignite | 0.158 | 18.0 | 0.09 | 1.75 |

Surface analysis of particulate samples was performed using ESCA. For SASS samples, these samples included cyclone and filter catches and for the RAC train, the particulate filter. Filter samples were analyzed by placing a small piece of the filter into the instrument's sample holder. Cyclone and other particulate were crushed, if necessary, and spread onto sintered steel substrates for subsequent analysis. Data were discarded if the resultant spectra displayed peaks characteristic of the substrate material. Regenerator bed material was also analyzed as a "particulate" sample to determine the fluid bed's effectiveness in removing sulfur from the coal. Lignite and limestone feed samples were also crushed and analyzed by ESCA. Analysis of impactor substrates was attempted, but due to the light particulate covering, no spectra could be obtained.

All samples analyzed by ESCA in this study were first scanned over the entire electron binding energy range (broadband scan) to identify those elements present in concentrations greater than 0.1 to 1 percent (the sensitivity of ESCA to any one element is a function of the photoionization cross-section of the most intense core electron emission of that element). These broadband spectra were then analyzed to yield surface concentrations of all identifiable elements. Representative broadband spectra appear in Figures 9 and 10. Quantification data for RAC particulate appear in Table 28; those for SASS samples in Table 29.

TABLE 28. QUANTIFICATION DATA FROM ESCA ANALYSES OF RAC TRAIN PARTICULATE FILTERS (RESULTS IN PERCENT ATOMIC)

| Element | RAC-1 | RAC-2 | RAC-3 | RAC-4 | RAC-5 |
|---|---|---|---|---|---|
| O | 55.5 | 49.1 | 54.6 | 51.9 | 51.4 |
| C | 19.3 | 24.1 | 23.4 | 23.9 | 27.4 |
| Ca | 5.3 | 4.8 | 4.2 | 3.5 | 5.0 |
| Na | - | 1.3 | - | - | - |
| S | 4.1 | 3.9 | 4.9 | 3.5 | 3.2 |
| Si | 6.8 | 5.9 | 5.4 | 7.9 | 6.6 |
| Al | 9.0 | 10.9 | 7.5 | 9.3 | 6.3 |

As can be seen from the quantification data, the particulate samples have very similar surface compositions, with oxygen and carbon being particularly abundant. Substantial portions of this carbon, which the carbon 1s short scans showed to be mostly hydrocarbon, and oxygen are due to unavoidable adsorption of these ubiquitous species on the sample surfaces. Such contamination is a common problem in surface analysis and makes absolute (rather than relative) quantification of the samples impossible.

The composition of particulate from lignite firing is quite different from that found in the oil-fired CAFB. Samples collected during oil runs contained no detectable aluminum or silicon; they had more sulfur and sodium and also contained vanadium due to the different compositions of the fuels. Analysis of fuel oil showed 20 ppm silicon and 2.1 ppm aluminum, while in lignite these elements are listed as major components of greater than 1 percent (10,000 ppm). Vanadium is present in lignite at 28 ppm and in fuel oil at 307 ppm.

Short scans over the binding energy range of the carbon 1s electron showed several distinct carbon species. Figures 11 and 12 are $C_{1s}$ spectra of SASS No. 1 filter and SASS No. 2 1μ particulate, respectively. Hydrocarbons are the dominant carbon species in both samples, and both show small amounts of surface carbonate. The tailing between the hydrocarbon and carbonate binding energies,

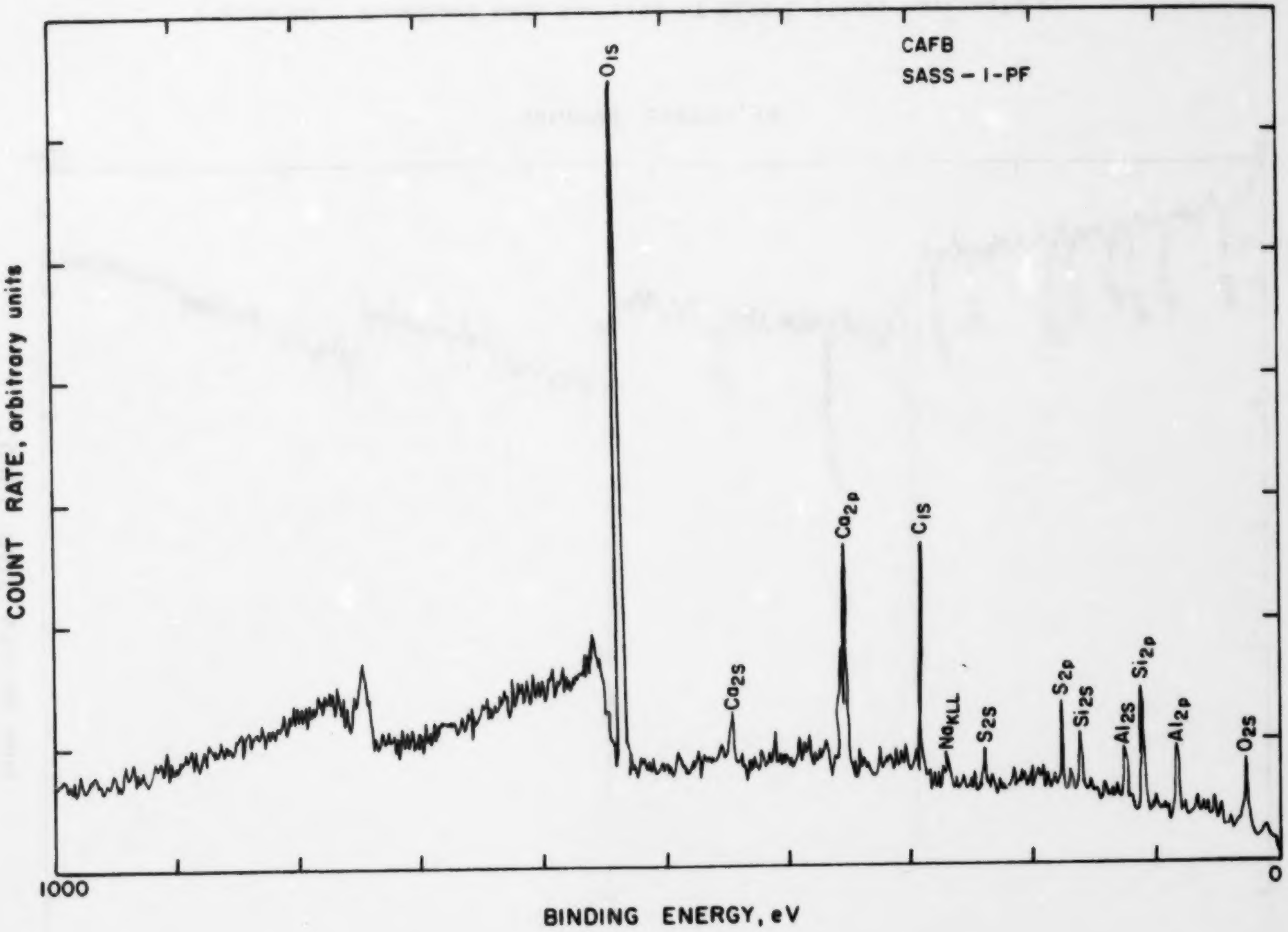

Figure 9. Broadband ESCA spectrum of SASS-1 filter particulate.

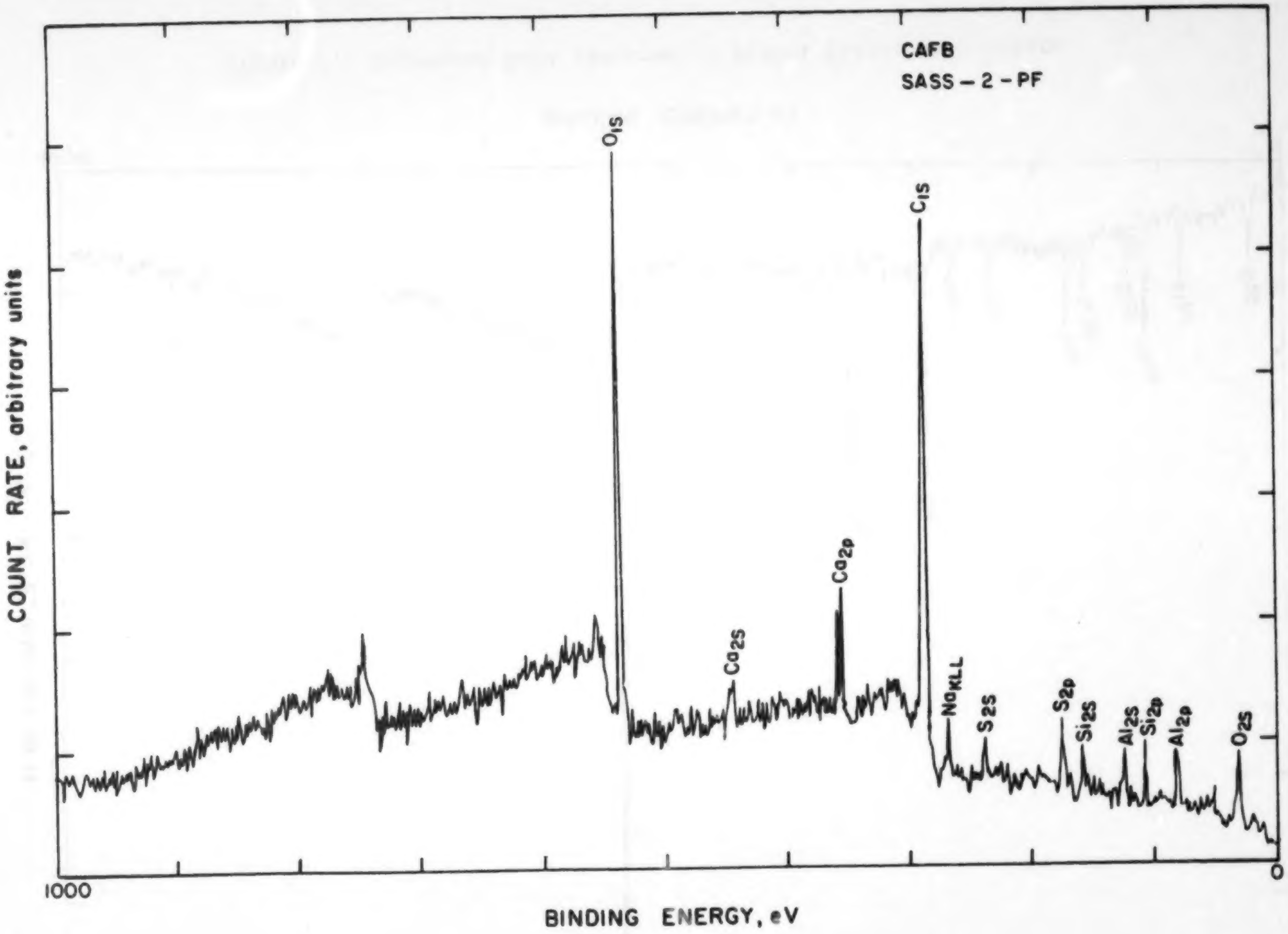

Figure 10. Broadband ESCA spectrum of SASS-2 filter particulate.

TABLE 29. ELEMENTAL QUANTIFICATION DATA FOR SASS PARTICULATE SAMPLES FROM ESCA ANALYSIS; RESULTS IN PERCENT ATOMIC

| | SASS run No. 1 | | | | SASS run No. 2 | | | |
|---|---|---|---|---|---|---|---|---|
| Element | Particulate filter | 1μ cyclone | 3μ cyclone | 10μ cyclone | Particulate filter | 1μ cyclone | 3μ cyclone | 10μ cyclone |
| O | 43.1 | 44.5 | 47.3 | 48.6 | 33.0 | * | 55.0 | 53.9 |
| C | 26.9 | 28.9 | 29.4 | 30.0 | 52.3 | * | 25.8 | 24.4 |
| Ca | 12.8 | 9.2 | 4.3 | 3.3 | 2.8 | * | 3.3 | 4.8 |
| Na | 0.6 | 0.7 | 0.8 | 0.6 | 1.0 | * | 0.8 | - |
| S | 4.7 | 6.9 | 6.1 | 7.7 | 3.7 | * | 6.3 | 10.5 |
| Si | 5.7 | 4.8 | 6.1 | 4.4 | 2.5 | * | 4.2 | 2.4 |
| Al | 6.3 | 5.0 | 6.0 | 5.4 | 4.6 | * | 4.7 | 4.0 |

*Calculations were not made due to high background in spectrum attributed to substrate.

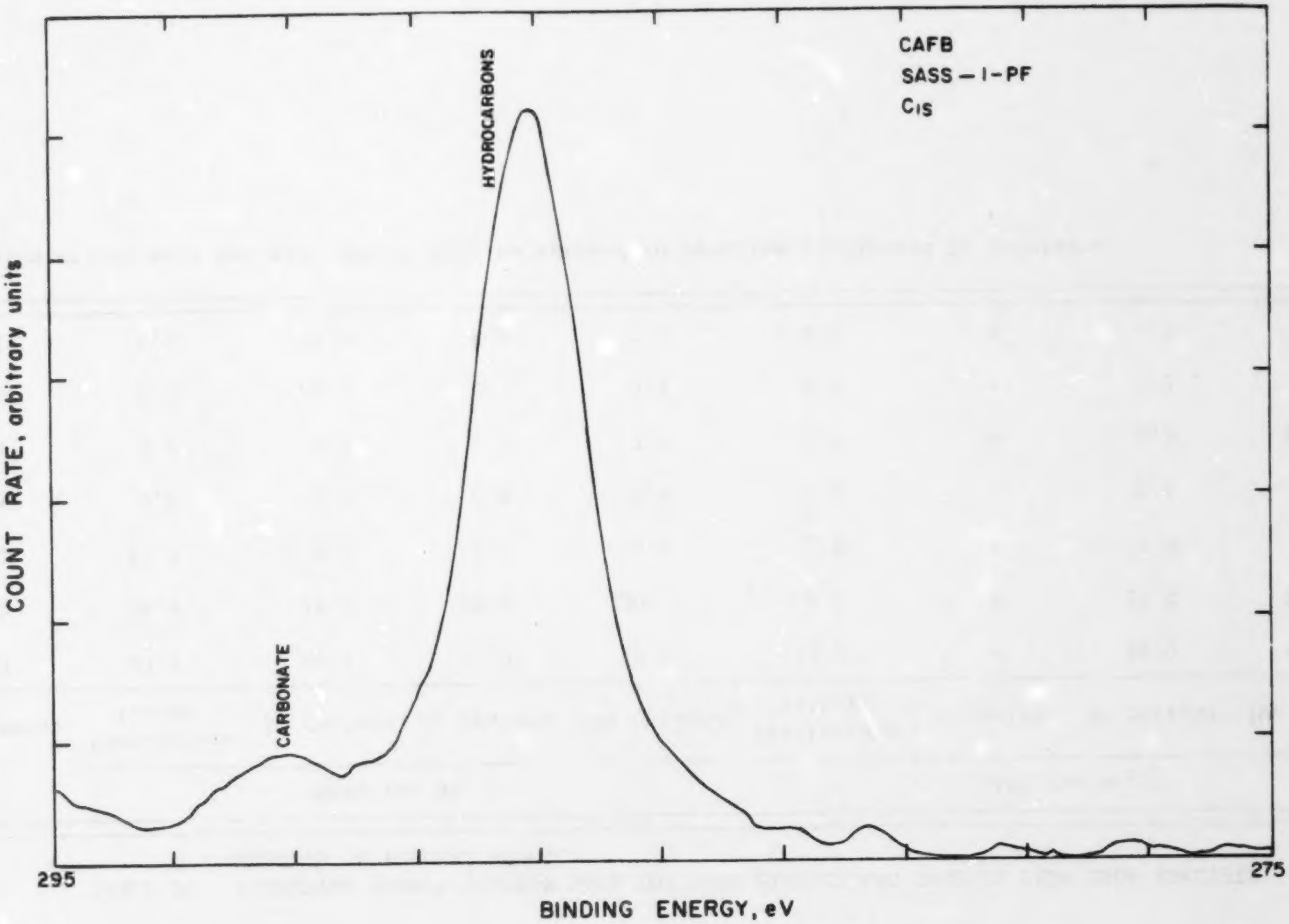

Figure 11. Carbon ls spectrum of SASS-1 filter particulate.

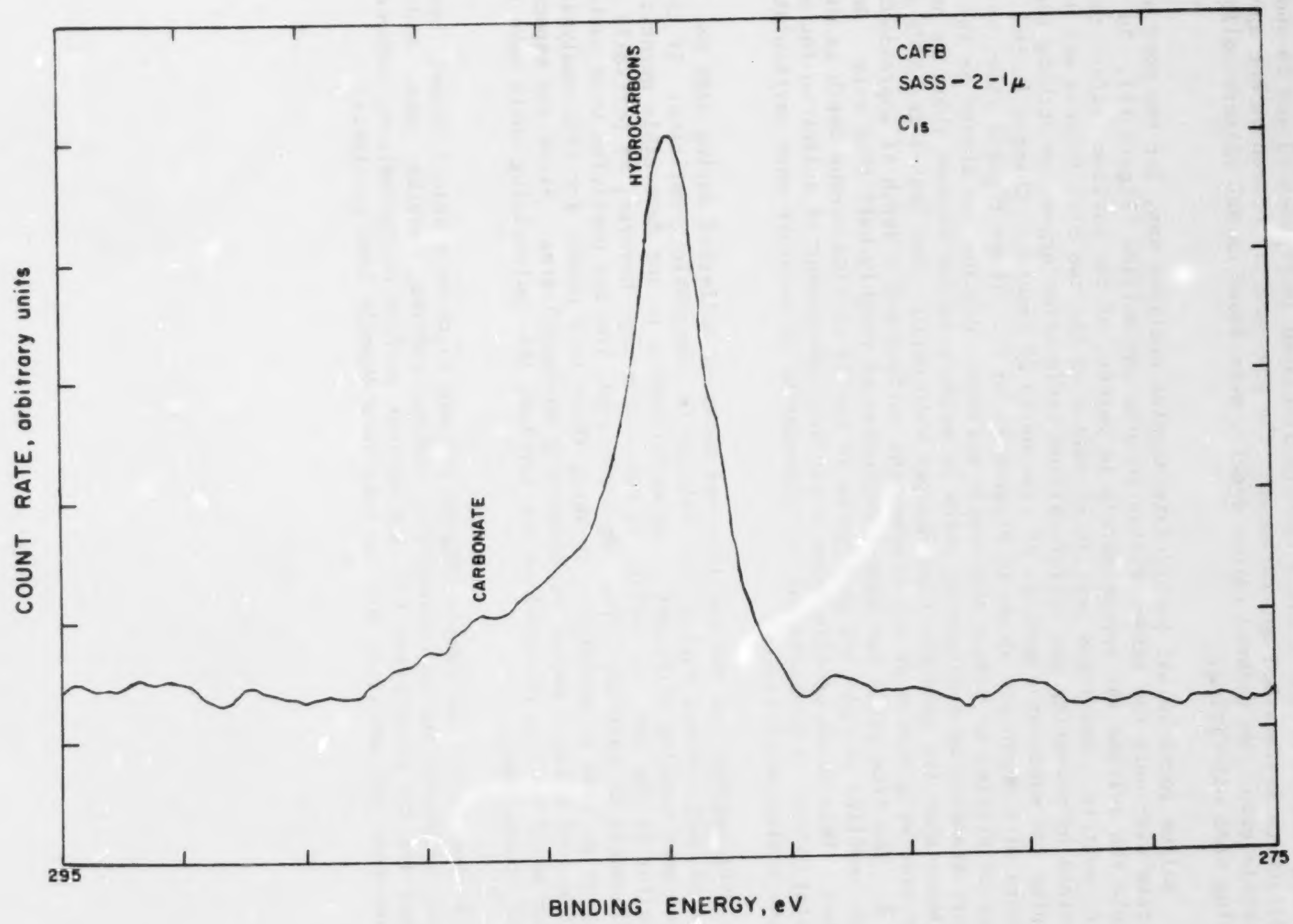

Figure 12. Carbon 1s spectrum of SASS-2 1μ cyclone particulate.

particularly evident in Figure 12, could be attributable to carbonyl or alcohol. The $C_{1s}$ spectra of RAC 1 and 5 filters displayed in Figures 13 and 14 show, in addition to hydrocarbon and carbonate, the presence of reduced carbon species, possibly coke. No reduced carbon species were found on RAC filters collected during CAFB oil-firing.

Sulfur found in all particulate samples analyzed was, for the most part, sulfate with only the SASS-2 filter showing any sulfide (Figure 15). In this sample the sulfide was approximately 10 percent of the surface sulfur; the rest, sulfate. The depth profile of sulfur on the two SASS filters was determined by measuring the sulfur-calcium ratio after argon ion etching the samples for successive periods of time up to 20 minutes. Changes in the spectra with depth are shown in Figures 15 to 17. These figures show the tendency of etching to reduce the sample surface. Calcium was chosen as the internal standard or constant by which to measure sulfur because there is no evidence that its concentration changes with depth. For SASS-1 the S/Ca ratio decreased by a factor of 4.5 between the surface and a depth of approximately 200 Å. The S/Ca ratio for SASS-2 decreased at roughly half that rate. Both depth profiles are plotted in Figures 18 and 19 as S/Ca versus depth as minutes etched. This depth profile shows a surface enhancement of sulfur on the particulate which is probably due to condensation of moisture onto particulate in the cooler stack region.

ESCA analysis of the gasifier bed material collected during SASS No. 2 revealed only carbon, oxygen, and calcium in detectable quantities. If the system were working efficiently, we would expect to see detectable quantities of sulfur in the bed. A failure to see sulfur may, however, be partially attributable to particle size. When received, the bed particles were perhaps as large as 1 mm in diameter. Crushing these to a powder for ESCA analysis would expose a large amount of previously unexposed area. Since any expected sulfur would be that adsorbed on the surface, this pulverizing could make the sulfur undetectable.

Carbon in the bed sample (Figure 20) was in three distinct forms: hydrocarbon, carbonate and an unidentified reduced species, possibly coke. Hydrocarbons are due to unburned fuel and ambient surface contamination; carbonate is limestone bed material; and the coke is a deposit from pyrolysis.

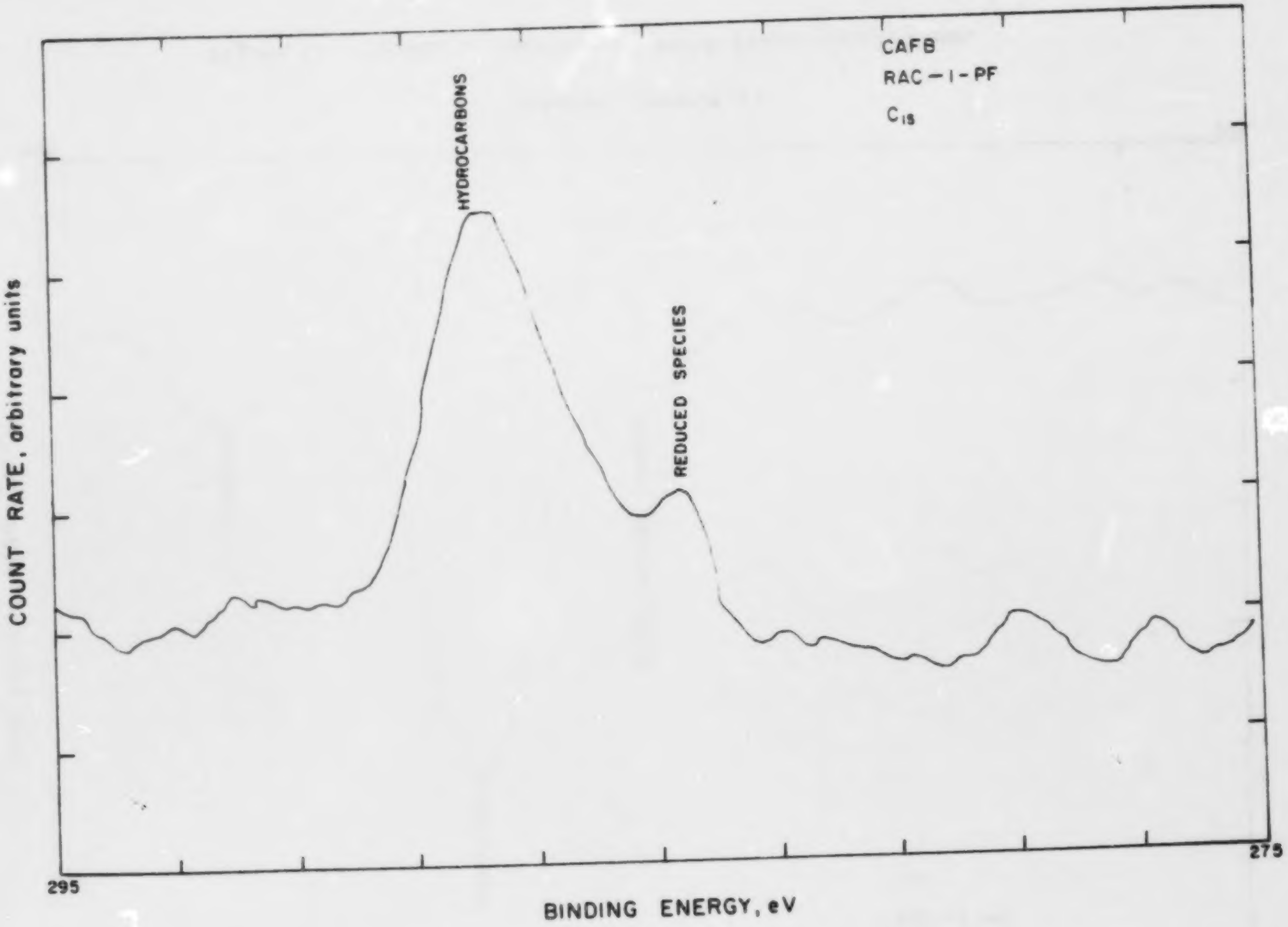

Figure 13. Carbon 1s spectrum of RAC-1 filter particulate.

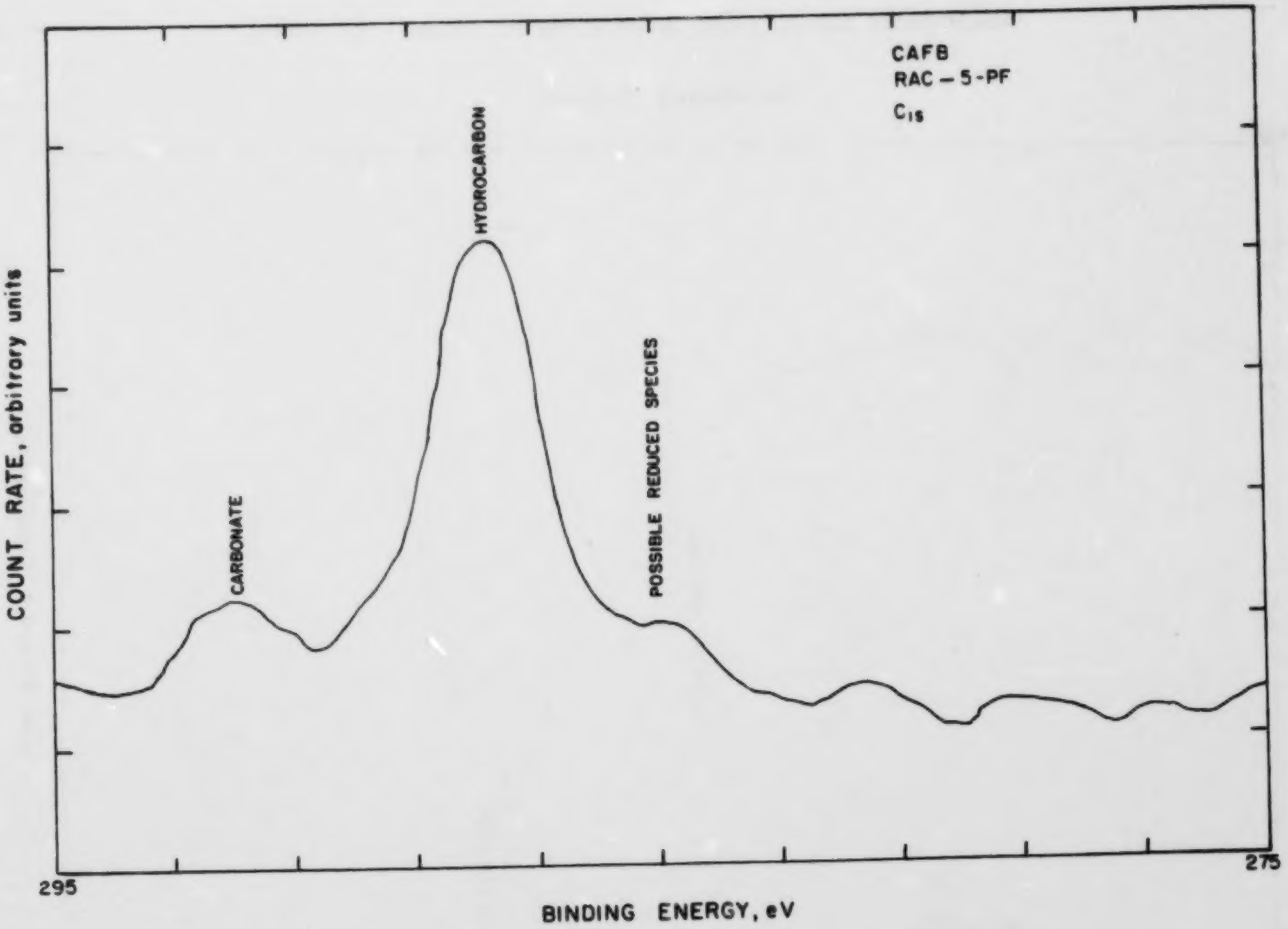

Figure 14. Carbon 1s spectrum of RAC-5 filter particulate.

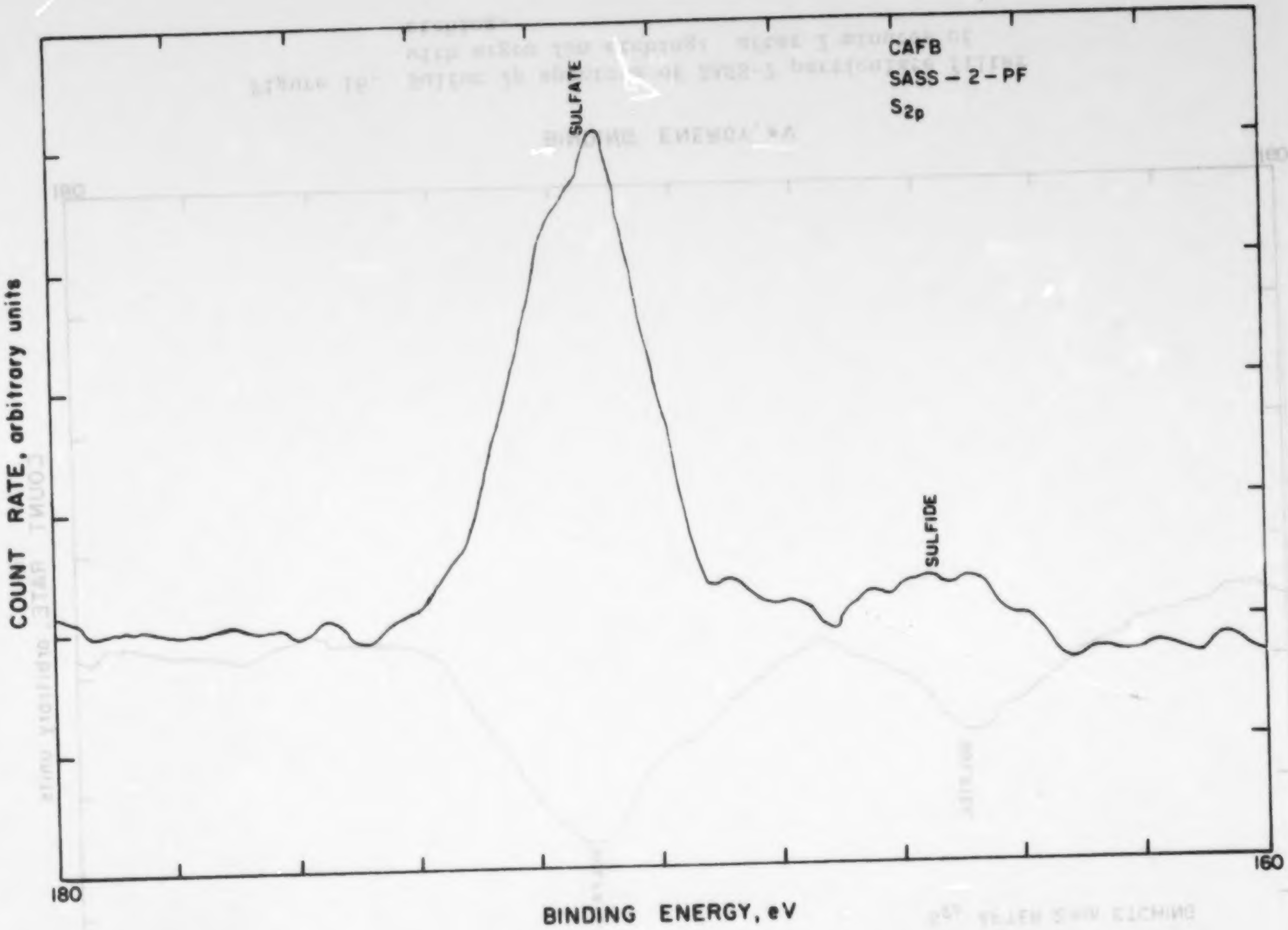

Figure 15. Sulfur 2p spectrum of SASS-2 filter particulate.

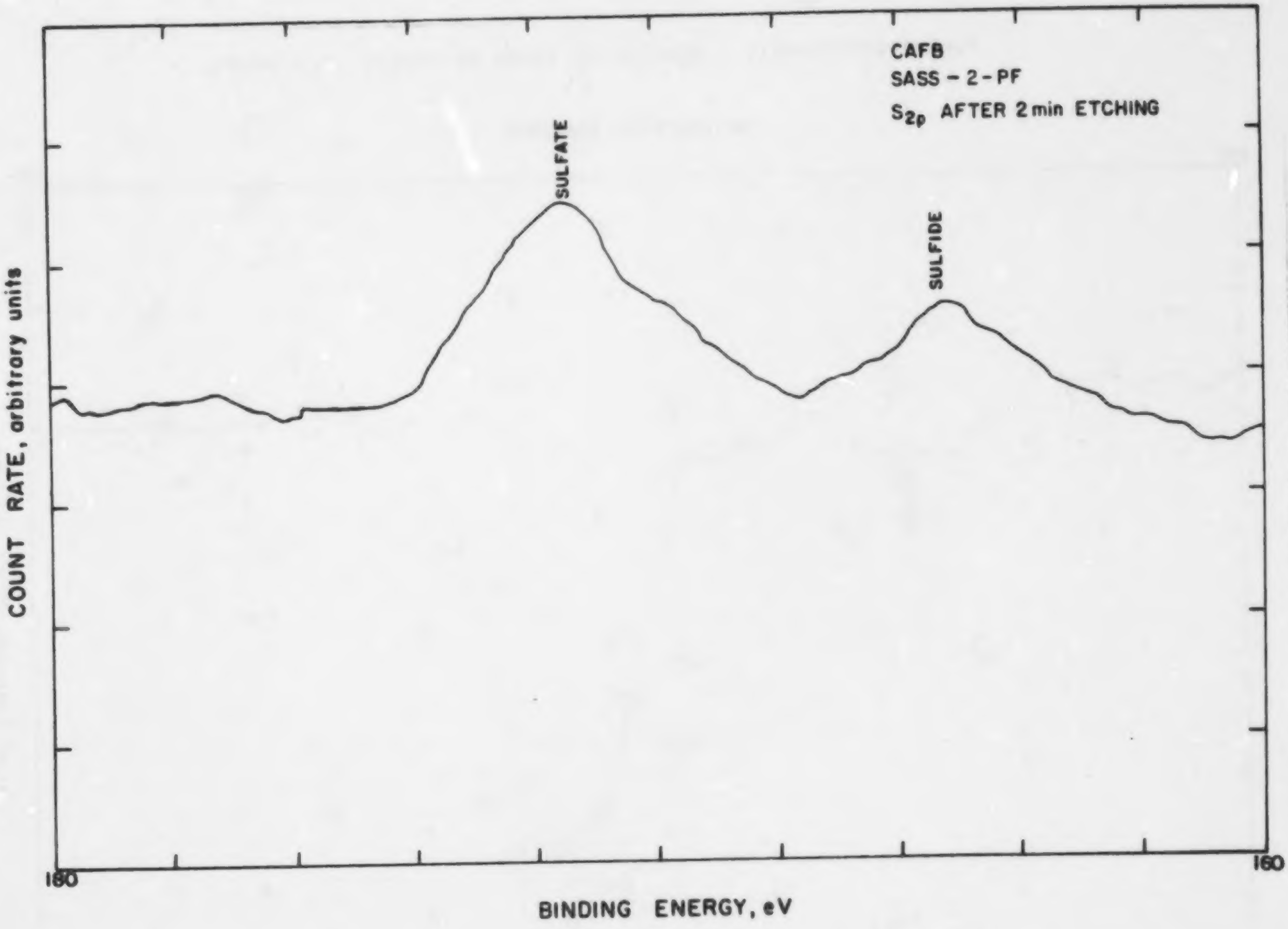

Figure 16. Sulfur 2p spectrum of SASS-2 particulate filter with argon ion etching: after 2 minutes of etching.

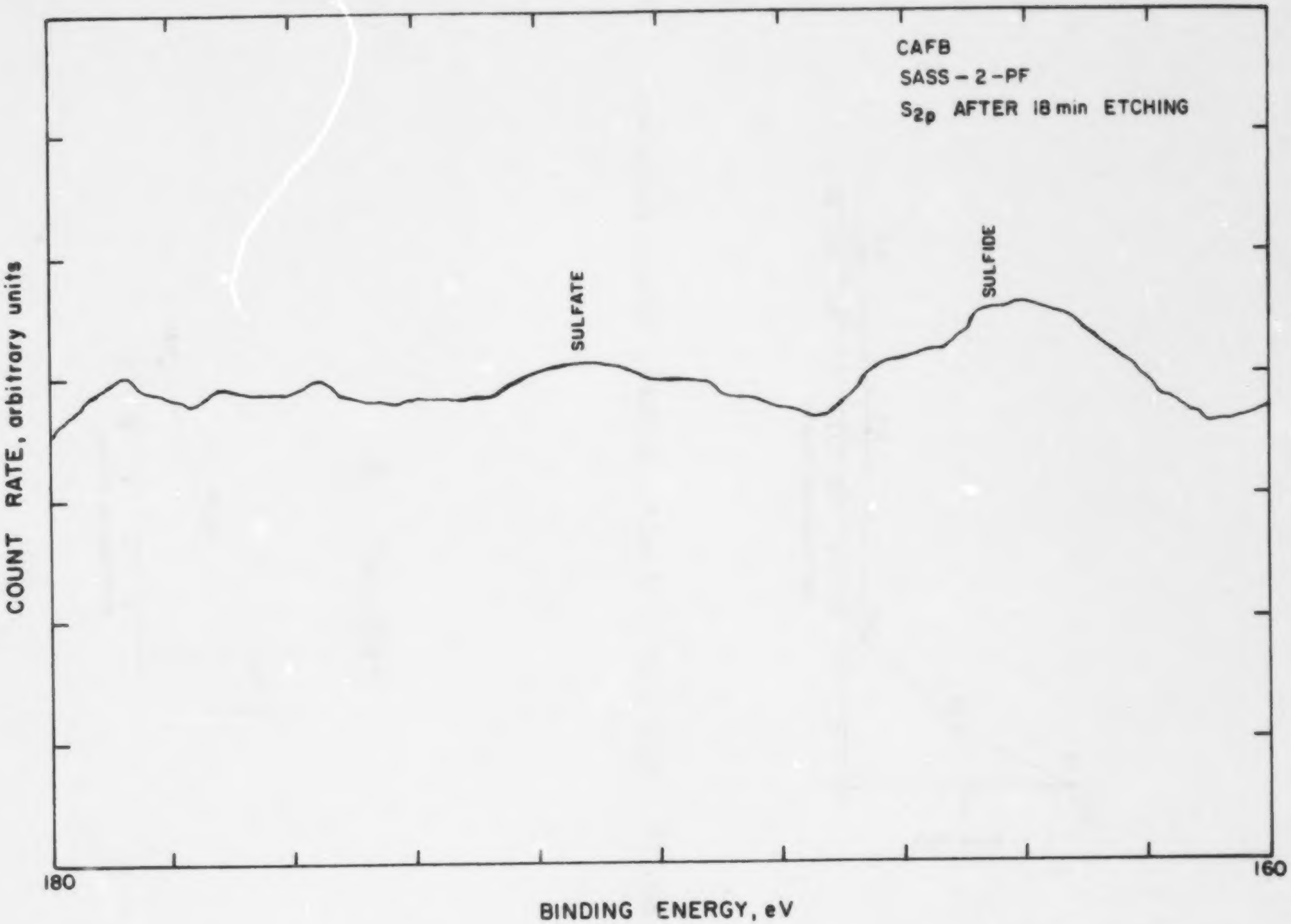

Figure 17. Sulfur 2p spectrum of SASS-2 particulate filter with argon ion etching: after 18 minutes of etching.

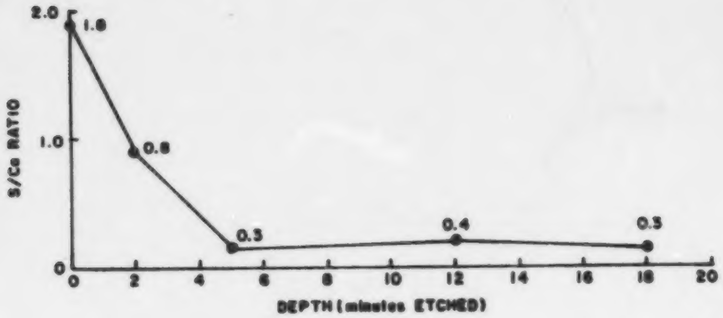

Figure 18. Depth profile of sulfur in SASS-1 filter particulate.

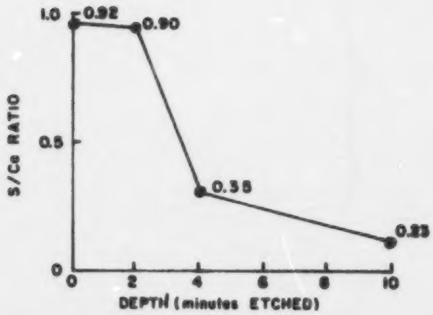

Figure 19. Depth profile of sulfur in SASS-2 filter particulate.

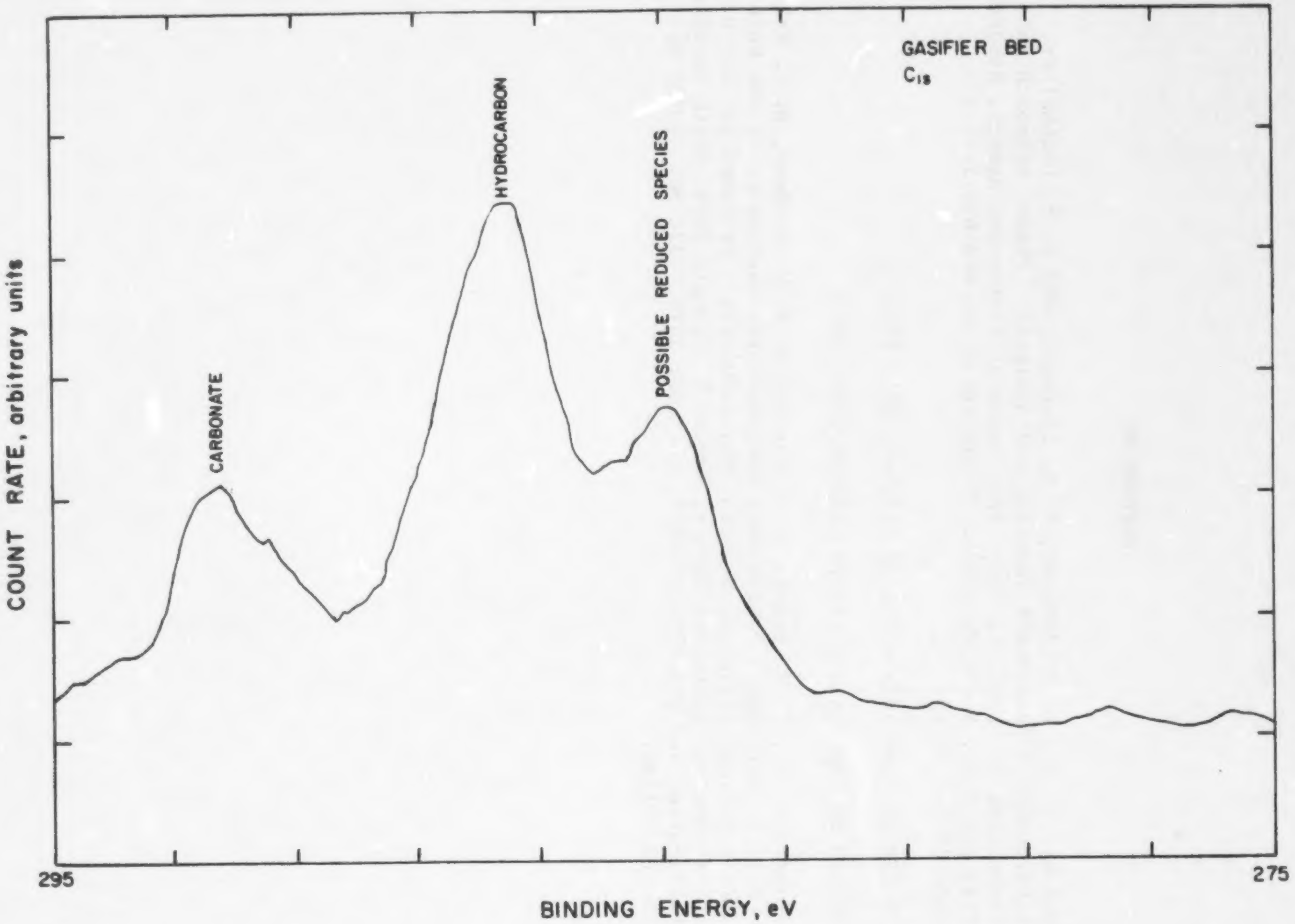

Figure 20. Carbon 1s spectrum of gasifier bed sample collected during SASS-2.

## REFERENCES

1. Dorsey, J. A., L. D. Johnson, R. M. Statnick, and C. H. Lochmuller. Environmental Assessment Sampling and Analysis: Phased Approach and Techniques for Level I. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/2-77-115. June 1977. 38 pp.

2. 40 CFR 60, Appendix A (42 FR 41754-41782), 1977.

3. 40 CFR 60, Appendix A (42 FR 41786-41789), 1977.

4. Werner, A. S., C. W. Young, M. I. Bornstein, R. M. Bradway, M. T. Mills, and D. F. Durocher. Preliminary Environmental Assessment of the CAFB. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/7-76-017. October 1976. 324 pp. (NTIS No. PB 262-001/AS).

# SECTION 5

# ENVIRONMENTAL ASSESSMENT

## INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of EPA is currently involved in formalizing and standardizing environmental assessment methods to allow for comparison of environmental impact associated with different energy and industrial processes. Source Analysis Models (SAM) have been developed by Acurex for EPA as a systematic procedure for investigating environmental impact.[1]

In conducting environmental assessments, it is necessary to perform one or more of the following tasks:

1. rank individual effluent streams by the expected toxicity of their discharges,
2. establish sampling priorities,
3. determine problem pollutants,
4. recommend best multimedia control technology alternatives,
5. recommend control/disposal technology development programs.

Three Source Analysis Models (SAM/IA, SAM/I, SAM/II) have been developed as a series of methods to aid in accomplishing these five tasks. GCA has employed the simplest method of the sequence, SAM/IA, to provide a rapid screening of flue gas emissions from the lignite-fired CAFB. SAM/IA compares actual emission and effluent concentrations with a series of Minimum Acute Toxicity Effluent (MATE) values established by EPA. The model is appropriate for analysis of Level I and Level II data and provides some input to each of the five elements above; most specifically: identification of further sampling needs, problem pollutants, and recommendations for applicable control technology. The objective in evaluating the CAFB by this procedure is to compare results with similar data derived for six conventional lignite-fired boilers located in the western U.S. The final goal is to recommend sampling procedures and control technology that would be appropriate for operation of the CAFB demonstration plant in San Benito, Texas.

SAM/IA is implemented by use of a tabular format for simple comparison of estimated pollutant discharge rates with effluent and emission goals. The emission goal used with SAM/IA is the MATE, with values established for most of the 650 substances on the Multimedia Environmental Goal (MEG) list based upon health or ecological effects reference data. The assumption is made that the concentrations of pollutants in gas, liquid or solid effluent streams should not exceed MATE values which are estimated to minimize acute (short-term exposure) toxic effects.

MATE's describe very approximate concentrations of components or species in air, water or land effluents which may evoke significant damage response in exposed humans or the ecology from limited duration exposures (i.e., less than 8 hours per day).

MATE's are derived from TLV's, NIOSH recommendations, $LD_{50}$'s, $LD_{LO}$'s, $LC_{50}$'s, $TD_{LO}$'s, TLM's, Water Quality Criteria and Drinking Water Regulations.

As many as six MATE's can be listed for each pollutant species or sample fraction in the worksheets:

- Air (health and ecology based)
- Water (health and ecology based)
- Land (health and ecology based).

This allows for comparison of emissions to MATE's for air, water or land for studies of health or ecological effects.

The steps included in the SAM/IA approach are:

1. Identify specific sources within the overall system or process.

2. Identify the various effluent streams from that source. For complete analysis, each gas, liquid or solid waste discharge is included as a separate effluent stream.

3. Determine the concentration of each sample fraction (Level I) or specific pollutant species (Level II) to be considered in each effluent stream. In Level I assessments, the set of species potentially present which would lead to environmental hazard is established at this point for each sample fraction.

4. Each sample fraction or specific pollutant concentration in a given effluent stream is then divided by its corresponding health-based MATE. This quantity is, henceforth, called a "degree of hazard" (H). A second quotient is formed using the corresponding ecological MATE.

5. At this point, flags (i.e., checkmarks) are noted on the form for each pollutant entry whose health or ecological degree of hazard (H) is greater than unity. This provides for ease in spotting potential problem pollutants. Their presence should be noted and assessed in any report.

6. The final calculation for each pollutant species or sample fraction in each stream utilizes the product of its degree of hazard (H) and the effluent stream flow rate to establish health (or ecological) toxic unit discharge rates (TUDR).

7. The total stream degree of hazard is then calculated as the sum of the H's for each pollutant. Further, the total stream TUDR is calculated by summing the individual pollutant entry toxic unit discharge rates.

8. Degrees of Hazard and Toxic Unit Discharge Rates are then grouped and summed by discharge media (i.e., the H's and TUDR's for all gaseous, water and solid effluent streams are listed and summed for each medium).

## GASEOUS EMISSIONS

SAM/IA is being used to assess air emissions from the CAFB as compared to several conventionally-fired lignite boilers in the Western U.S. Particulate and trace element and anion species are compared based on sampling by SASS and RAC train methods and analysis by spark source mass spectroscopy (SSMS), atomic absorption spectroscopy (AAS), and wet chemical techniques. Other air emissions which are assessed in the SAM/IA model include: $C_1$-$C_6$ hydrocarbons, $NO_x$, $SO_2$ and $SO_3$.

Table 30 illustrates the format of the SAM/IA procedure and an analysis of gaseous emissions measured during lignite gasification and combustion. No hydrocarbons with higher boiling points than $C_2$ were detected, and hydrocarbons which did exist were in very low concentrations. Comparison of actual hydrocarbon concentrations with health MATE values shows degrees of hazard significantly less than 1. However, the ecological degree of hazard for $C_1$ hydrocarbons, 9,000, indicates that flue gas ethylene concentrations may have an adverse effect on vegetation. The ecological $C_1$ hydrocarbon MATE value was probably set at 1 $\mu g/m^3$ due to the reported harmful effect of ethylene on plants at relatively low concentrations. The SAM/IA analysis indicates that $C_2$ hydrocarbons (acetylene, ethane, propylene) emitted from the CAFB during lignite gasification are low and of minor significance in producing adverse health or ecological impacts.

The health hazard factors associated with NO and $NO_x$ emissions range from 3.1 to 4.1, respectively. This indicates a somewhat excessive emission of nitrogen oxides, however, on a fuel-related basis $NO_x$ emissions are well below the new source performance standards (NSPS) for coal-fired steam generators $> 250 \times 10^6$ Btu/hr capacity. The actual $NO_x$ emission rate is 0.09 lb/$10^6$ Btu as compared to the standard of 0.7 lb/$10^6$ Btu, lower by a factor of 10. This suggests that the health MATE value for $NO_x$ may require revision to make it more representative of existing standards.

TABLE 30. SAM/IA WORKSHEET FOR LEVEL 1 - ESSO, ENGLAND, CAFB PILOT PLANT

**SAM/IA WORKSHEET FOR LEVEL 1**

**Form IA02 Level 1**

Page 1

1. SOURCE/CONTROL OPTION

ESSO, England, CAFB Pilot Plant

2. EFFLUENT STREAM

101 Flue Gas

CODE # NAME

3. EFFLUENT STREAM FLOW RATE

Q = 0.6 $m^3/sec$

(gas = $m^3/sec$ — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCEN TRATION | HEALTH MATE CONCEN TRATION | ECOLOGICAL MATE CONCEN TRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E × LINE 3) | (ECOLOGICAL BASED) (G × LINE 3) |
| UNITS | $\mu g/m^3$ | $\mu g/m^3$ | $\mu g/m^3$ | – | – | – | – | – | – | | |
| $C_1$ | 9.0E3 | 3.3E5 | 1.0 | 0.03 | - | 9,000 | 2 | | ✓ | 0.02 | 5,355 |
| $C_2$ | 2.0E3 | 5.3E6 | 1.1E5 | 0.0004 | - | 0.02 | 2 | | | 0.0002 | 0.01 |
| NO | 2.8E4 | 9.0E3 | N | 3.1 | | | | ✓ | | 1.84 | |
| $NO_x$ | 3.7E4 | 9.0E3 | N | 4.1 | | | | ✓ | | 2.44 | |
| $SO_2$ | 5.1E5 | 1.3E4 | N | 39.2 | | | | ✓ | | 23.52 | |
| $SO_3$ | 3.2E3 | N | N | | | | | | | | |
| CO | <5.7E5 | 4.0E4 | 1.2E5 | <14.3 | | 4.75 | | ✓ | ✓ | 8.51 | 2.83 |
| $CO_2$ | 1.4E8 | 9.0E6 | N | 15.6 | | | | ✓ | | 9.28 | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 76.3

ECOLOGICAL MATE BASED (Σ COL. G) 5b 9,005

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 7

ECOLOGICAL 6b 3

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a 45.6

ECOLOGICAL MATE BASED (Σ COL. L) 7b 5,358

(ENTER HERE AND AT LINE 8, FORM IA01)

The same argument holds for the SAM/IA results for $SO_2$ emissions. Although the health hazard factor is 39.2, the total $SO_2$ emission was found to be 0.55 $lb/10^6$ Btu or less than half of the NSPS (1.2 $lb/10^6$ Btu) for large steam generators. The emission of $CO_2$ and attendant hazard factor is fairly meaningless because high $CO_2$ flue gas concentrations are indicative of high combustion efficiency.

## TRACE ELEMENT AIR EMISSIONS

The SAM/IA procedure was used to assess the impact of trace element emissions measured during the lignite run at the ESSO pilot plant. Tables 31 and 32 present a listing of trace element concentrations measured by spark source mass spectrometry (SSMS) from particulate samples collected during the two SASS runs. As for the gaseous emission analysis, emissions and MATE values are presented in $\mu g/m^3$. A check mark is placed in column I or J if the Health or Ecology MATE value is exceeded by the actual emission. For the first SASS run (SASS-1), the emissions of concern, according to the SAM/IA analysis, include Ba, As, Ni, Cr, V (Ecology MATE exceeded), Ti, P, Si, Mg, B, and Be. Except for Ti, Si, Mg, and B, these emissions may have severe effects. RTI's research of background information for MEG (multimedia environmental goal) development reports the following potential effects associated with the aforementioned hazardous trace elements:[2]

- Barium - soluble barium compounds are highly toxic when ingested; 0.8 to 0.9 g of $BaCl_2$ is reported as a lethal dose; BaO and $BaCO_3$ have caused respiratory damage in man.
- Arsenic - trivalent species is most toxic; compounds absorbed by inhalation, ingestion, and through skin; cumulative poison producing chronic effects in mammals.
- Nickel - nickel absorbed through inhalation may be associated with nasal, sinus, and lung cancer; dietary intake of nickel apparently not harmful; nickel salts may be highly toxic.
- Chromium - all chromium compounds are considered poisonous, with hexavalent chromium considered more hazardous than trivalent form; inhalation may cause injury or cancer in the respiratory tract; laboratory tests have shown carcinogenic response in rats and mice with lowest dosage of 1 mg/kg.
- Vanadium - toxic to humans by all routes of absorption, with pentavalent species being most highly toxic; inhalation causes respiratory system effects, including tracheitis, pulmonary edema, and bronchial pneumonia; 0.2 to 0.5 $mg/m^3$ has caused effects on respiratory systems; 0.5 to 1.0 $\mu g/m^3$ has produced noticeable effects in plants.
- Phosphorus - white phosphorus is most hazardous allotropic form; chronic effects include liver injury, necrosis of jaw bone, anemia, brittle bones, and tooth and eye damage; may be absorbed by all

TABLE 31. SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

**SAM/IA WORKSHEET FOR LEVEL 1**

**Form IA02 Level 1**

1. SOURCE/CONTROL OPTION

Page 1 /

ESSO, England, CAFB Pilot Plant, SASS-1

2. EFFLUENT STREAM

101 Flue gas

CODE # NAME

3. EFFLUENT STREAM FLOW RATE

Q = 0.52 $m^3$/sec

(gas = $m^3$/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E × LINE 3) | (ECOLOGICAL BASED) (G × LINE 3) |
| UNITS | μg/$m^3$ | | | — | — | — | — | — | — | | |
| U | 18 | | | | | | | | | | |
| Th | 46 | | | | | | | | | | |
| Bi | 0.6-35 | 4.1E2 | N | .001-.085 | | | | | | .0005-.04 | |
| Pb | 200 | | | | | | | | | | |
| Tl | < 2.1 | 1.5E2 | N | <0.014 | | | | | | <0.01 | |
| Au | < 2.1 | N | N | | | | | | | | |
| Ir | < 3.2 | | | | | | | | | | |
| Os | < 3.5 | | | | | | | | | | |
| Re | < 2.2 | | | | | | | | | | |
| W | < 6.1 | 1.0E3 | N | <0.006 | | | | | | <0.003 | |
| Hf | <24 | | | | | | | | | | |
| Lu | < 6.2 | | | | | | | | | | |
| Yb | < 5.9 | | | | | | | | | | |
| Tm | < 1.1 | | | | | | | | | | |

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a ~513

ECOLOGICAL MATE BASED (Σ COL. G) 5b 310

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 31

ECOLOGICAL 6b 1

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a ~267

ECOLOGICAL MATE BASED (Σ COL. L) 7b 161

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE 31 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

**CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1**

Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-1

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | TOXIC UNIT DISCHARGE RATE |  |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | ✓ IF HEALTH MATE EXCEEDED | ✓ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | μg/m$^3$ |  |  | — | — | — | — | — | — |  |  |
| Er | < 6.9 |  |  |  |  |  |  |  |  |  |  |
| Ho | <0.1-2.3 |  |  |  |  |  |  |  |  |  |  |
| Dy | 0.2-9.4 | 9.3E3 | N | <0.001 |  |  |  |  |  | <0.0005 |  |
| Tb | < 0.3 |  |  |  |  |  |  |  |  |  |  |
| Gd | < 4.6 |  |  |  |  |  |  |  |  |  |  |
| Eu | 0.6-3.4 |  |  |  |  |  |  |  |  |  |  |
| Sm | 3.3-16.0 | 5.3E4 | N | <0.0003 |  |  |  |  |  | <0.00002 |  |
| Nd | 31 | N | N |  |  |  |  |  |  |  |  |
| Pr | 10 | 5.1E4 | N | 0.0002 |  |  |  |  |  | 0.0001 |  |
| Ce | 98 | 3.7E4 | N | 0.0026 |  |  |  |  |  | 0.0014 |  |
| La | 200 | 1.1E5 | N | 0.0018 |  |  |  |  |  | 0.0009 |  |
| Ba | 2,800 | 5.0E2 | N | 5.6 |  |  |  | ✓ |  | 2.91 |  |
| Cs | 3.7 |  |  |  |  |  |  |  |  |  |  |
| I | 1.3 |  |  |  |  |  |  |  |  |  |  |
| Te | 8.8 | 1.0E2 | N | 0.088 |  |  |  |  |  | 0.046 |  |
| Sb | 7.2 | 5.0E2 | N | 0.014 |  |  |  |  |  | 0.007 |  |
| Sn | 71 | N | N |  |  |  |  |  |  |  |  |
| Cd | 5.4 | 1.0E1 | N | 0.54 |  |  |  |  |  | 0.281 |  |
| Pd | 7.9 |  |  |  |  |  |  |  |  |  |  |
| Ph | 0.9 |  |  |  |  |  |  |  |  |  |  |
| Ru | < 1.9 |  |  |  |  |  |  |  |  |  |  |
| Mo | 8.4 | 5.0E3 | N | 0.002 |  |  |  |  |  | 0.001 |  |
| Nb | 81 |  |  |  |  |  |  |  |  |  |  |
| Zr | 510 |  |  |  |  |  |  |  |  |  |  |
| Y | 120 |  |  |  |  |  |  |  |  |  |  |

TABLE 31 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

**CONTINUATION SHEET FOR ITEM NO. 1, FORM IA02, LEVEL 1**

Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-1 EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | μg/m$^3$ | | | — | — | — | — | — | — | | |
| Sr | 2,600 | 3.1E3 | N | 0.839 | | | | | | 0.436 | |
| Rb | 50 | | | | | | | | | | |
| Br | 160 | | | | | | | | | | |
| Se | 0.6-75 | 2.0E2 | N | .003-.375 | | | | | | <0.195 | |
| As | 650 | 2.0 | N | 325 | | | | ✓ | | 169 | |
| Ge | 6.2-33 | 5.6E2 | N | .011-.059 | | | | | | <0.031 | |
| Ga | 170 | 5.0E3 | N | 0.034 | | | | | | 0.018 | |
| Zn | 860 | 4.0E3 | N | 0.215 | | | | | | 0.112 | |
| Cu | 180 | 2.0E2 | N | 0.90 | | | | | | 0.468 | |
| Ni | 230 | 1.5E1 | N | 15.33 | | | | ✓ | | 7.97 | |
| Co | 48 | 5.0E1 | N | 0.96 | | | | | | 0.50 | |
| Fe | - | | | | | | | | | | |
| Mn | 1,700 | 5.0E3 | N | 0.34 | | | | | | 0.177 | |
| Cr | 110 | 1 | N | 110 | | | | ✓ | | 57.2 | |
| V | 310 | 5.0E2 | 1 | 0.62 | | 310 | | | ✓ | 0.322 | 161 |
| Ti | 13,000 | 6.0E3 | N | 2.17 | | | | ✓ | | 1.128 | |
| Ca | 210,000 | | | | | | | | | | |
| K | 11,000 | N | N | | | | | | | | |
| S | - | | | | | | | | | | |
| P | 1,600 | 1.0E2 | N | 16 | | | | ✓ | | 8.32 | |
| Si | 230,000 | 1.0E4 | N | 23 | | | | ✓ | | 11.96 | |
| Al | - | 5.2E3 | N | | | | | | | | |
| Mg | 16,000 | 6.0E3 | N | 2.67 | | | | ✓ | | 1.388 | |
| Na | - | 5.3E4 | N | | | | | | | | |
| B | 4,300 | 3.1E3 | N | 1.387 | | | | ✓ | | 0.721 | |
| Be | 14 | 2.0 | N | 7 | | | | ✓ | | 3.64 | |

TABLE 32. SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

**SAM/IA WORKSHEET FOR LEVEL 1** **Form IA02 Level 1**

1 SOURCE/CONTROL OPTION Page 1

ESSO, England, CAFB Pilot Plant, SASS-2

2 EFFLUENT STREAM

101 (CODE #) Flue gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 0.60 $m^3$/sec

(gas = $m^3$/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E × LINE 3) | (ECOLOGICAL BASED) (G × LINE 3) |
| UNITS | ug/$m^3$ | | | — | — | — | — | — | — | | |
| U | 13 | | | | | | | | | | |
| Th | 35 | | | | | | | | | | |
| Bi | 0.5-28 | 4.1E2 | N | .001-.068 | | | | | | <0.041 | |
| Pb | 310 | | | | | | | | | | |
| Tl | < 13 | 1.5E2 | N | <0.087 | | | | | | <0.052 | |
| Au | < 13 | N | N | | | | | | | | |
| Ir | < 20 | | | | | | | | | | |
| Os | < 22 | | | | | | | | | | |
| Re | < 14 | | | | | | | | | | |
| W | < 23 | 1.0E3 | N | <0.023 | | | | | | <0.014 | |
| Hf | < 49 | | | | | | | | | | |
| Lu | < 13 | | | | | | | | | | |
| Yb | < 12 | | | | | | | | | | |
| Tm | < 5.8 | | | | | | | | | | |

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a ~920

ECOLOGICAL MATE BASED (Σ COL. G) 5b 430

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 31

ECOLOGICAL 6b 1

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a ~551

ECOLOGICAL MATE BASED (Σ COL. L) 7b 258

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE 32 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

**CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1**

Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-2

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | TOXIC UNIT DISCHARGE RATE |  |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | ✓ IF HEALTH MATE EXCEEDED | ✓ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | μg/m³ |  |  | — | — | — | — | — | — |  |  |
| Er | < 18 |  |  |  |  |  |  |  |  |  |  |
| Ho | < 6.2 |  |  |  |  |  |  |  |  |  |  |
| Dy | < 19 | 9.3E3 | N | <0.002 |  |  |  |  |  | <0.0012 |  |
| Tb | < 2.2 |  |  |  |  |  |  |  |  |  |  |
| Gd | < 14 |  |  |  |  |  |  |  |  |  |  |
| Eu | <0.1-8.1 |  |  |  |  |  |  |  |  |  |  |
| Sm | 1.1-31 | 5.3E4 | N | <0.001 |  |  |  |  |  | <0.0006 |  |
| Nd | 17-44 | N | N |  |  |  |  |  |  |  |  |
| Pr | 11 | 5.1E4 | N | 0.0002 |  |  |  |  |  | 0.00012 |  |
| Ce | 97 | 3.7E4 | N | 0.003 |  |  |  |  |  | 0.00018 |  |
| La | 200 | 1.1E5 | N | 0.002 |  |  |  |  |  | 0.00012 |  |
| Ba | 5,100 | 5.0E2 | N | 10.2 |  |  |  | ✓ |  | 6.12 |  |
| Cs | 3.5 |  |  |  |  |  |  |  |  |  |  |
| I | 2.7-12 |  |  |  |  |  |  |  |  |  |  |
| Te | 0.1-15 | 1.0E2 | N | .001-.15 |  |  |  |  |  | <0.09 |  |
| Sb | 18 | 5.0E2 | N | 0.036 |  |  |  |  |  | 0.022 |  |
| Sn | 18-400 | N | N |  |  |  |  |  |  |  |  |
| Cd | 2.0-27 | 1.0E1 | N | 0.2-2.7 |  |  |  | ✓ |  | <1.62 |  |
| Pd | < 16 |  |  |  |  |  |  |  |  |  |  |
| Rh | < 3.9 |  |  |  |  |  |  |  |  |  |  |
| Ru | < 13 |  |  |  |  |  |  |  |  |  |  |
| Mo | 12 | 5.0E3 | N | 0.002 |  |  |  |  |  | 0.0012 |  |
| Nb | 78 |  |  |  |  |  |  |  |  |  |  |
| Zr | 540 |  |  |  |  |  |  |  |  |  |  |
| Y | 87 |  |  |  |  |  |  |  |  |  |  |
| Sr | 5,000 | 3.1E3 | N | 1.613 |  |  |  | ✓ |  | 0.968 |  |

TABLE 32 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

**CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1**

Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-2 EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3) | TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | μg/m³ | | | — | — | — | — | — | — | | |
| Rb | 63 | | | | | | | | | | |
| Br | 190 | | | | | | | | | | |
| Se | 14-160 | 2.0E2 | N | .07-0.80 | | | | | | <0.48 | |
| As | 1,000 | 2.0 | N | 500 | | | | ✓ | | 300 | |
| Ge | 41 | 5.6E2 | N | | | | | | | | |
| Ga | 260 | 5.0E3 | N | 0.052 | | | | | | 0.031 | |
| Zn | 1,900 | 4.0E3 | N | 0.475 | | | | | | 0.285 | |
| Cu | 260 | 2.0E2 | N | 1.30 | | | | ✓ | | 0.78 | |
| Ni | 130-630 | 1.5E1 | N | 8.67-42 | | | | ✓ | | <25.2 | |
| Co | 44 | 5.0E1 | N | 0.88 | | | | | | 0.528 | |
| Fe | - | | | | | | | | | | |
| Mn | 2,000 | 5.0E3 | N | 0.4 | | | | | | 0.24 | |
| Cr | 330 | 1 | N | 330 | | | | ✓ | | 198 | |
| V | 430 | 5.0E2 | 1 | 0.86 | | 430 | | | | 0.516 | 258 |
| Ti | 14,000 | 6.0E3 | N | 2.33 | | | | ✓ | | 1.398 | |
| Ca | - | | | | | | | | | | |
| K | 7,700 | N | N | | | | | | | | |
| S | 220,000 | | | | | | | | | | |
| P | 1,600 | 1.0E2 | N | 16 | | | | ✓ | | 9.6 | |
| Si | - | 1.0E4 | N | | | | | | | | |
| Al | - | 5.2E3 | N | | | | | | | | |
| Mg | 15,000 | 6.0E3 | N | 2.5 | | | | ✓ | | 1.5 | |
| Na | 5000-14,000 | 5.3E4 | N | .094-.264 | | | | | | <0.158 | |
| B | 3,100 | 3.1E3 | N | 1 | | | | ✓ | | 0.6 | |
| Be | 3.8 | 2.0 | N | 1.9 | | | | ✓ | | 1.14 | |
| Li | 60 | 2.2E1 | N | 2.73 | | | | ✓ | | 1.638 | |

routes; lowest reported lethal dose to humans is 1.4 mg/kg administered orally.

- Beryllium - toxic through all routes of absorption, with major health hazard via inhalation; chronic exposure causes berylliosis, with particle size being critical factor; lowest toxic concentration reported for humans is 0.1 mg/m$^3$; beryllium and 5 beryllium compounds reported to cause cancer in animals with lowest dose producing carcinogenic response being 35 μg/m$^3$ as $BeSO_4 \cdot 4H_2O$ in laboratory testing.

Because the toxicities of the elements reported are high, it is important to assure highly efficient control in actual commercial CAFB systems. It is expected that these trace elements are emitted in particulate form, but further Level II testing is required to identify actual compounds and the probability of escape in the vapor phase.

Using the SAM/IA procedure, analysis of particulate emitted during the second SASS run (SASS-2), during which emissions exceeded SASS-1 values by 25 percent, indicates some additional trace elements with health hazard factors greater than 1; namely, Cd, Sr, Cu, and Li. The naturally occurring isotope of Sr is not highly toxic, but the other three elements are, giving further support to the need for appropriate emission control in commercial systems.

The health hazard factors for the trace elements discussed above range from approximately 1 to 500 (covering SASS-1 and SASS-2); the highest value is for arsenic. The only trace element compared with an ecology MATE is vanadium, with ecology hazard factors of 310 and 430 for SASS-1 and SASS-2, respectively. These high hazard factors indicate that particulate control efficiency of 99.8 percent is required to lower the arsenic hazard factor to 1. Due to inconsistencies between MATE values and standards (e.g., the previous discussion of $NO_x$ and $SO_2$), it would be inappropriate to base control efficiency objectives solely on the results of the SAM/IA analysis. Therefore, we have evaluated (through application of the SAM/IA method) trace element emission data representing lignite-fired conventional boilers controlled with multiclones or electrostatic precipitators to compare conventional systems with the CAFB. These sites are located in the midwest and were recently monitored as part of another EPA contract.[3]

Site A is a conventional lignite-fired boiler using multiclones for particulate control. The total measured particulate emission at Site A is ~8.5 gm/m$^3$ as compared to ~2.5 gm/m$^3$ at the ESSO pilot plant. The results of the SAM/IA analysis of trace element emissions from the boiler are itemized in Table 33. The trace elements with hazard factors greater than 1 are the same as those noted during the SASS-1 and SASS-2 sampling runs at the ESSO pilot plant. Cobalt and manganese are also shown as having health hazard factors greater than 1. Overall, the hazard factors for these important elements range between 1 and 800, which is very similar to the CAFB results. It is important to note that the accuracy of the SSMS technique is within a factor of 2 or 3 so that differences of an order of magnitude are necessary to be significant. Overall, the ESSO pilot plant trace element emissions present no

TABLE 33. SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

**SAM/IA WORKSHEET FOR LEVEL 1**

**Form IA02 Level 1**

1. SOURCE/CONTROL OPTION

Conventional Lignite Boiler With Multiclone - Site A

Page 1

2. EFFLUENT STREAM

101 (CODE #) Flue Gas (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 27.9 $m^3$/sec

(gas = $m^3$/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | TOXIC UNIT DISCHARGE RATE |  |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | ug/$m^3$ | ug/$m^3$ |  | — | — | — | — | — | — |  |  |
| U | 56 |  |  |  |  |  |  |  |  |  |  |
| Th | 74 |  |  |  |  |  |  |  |  |  |  |
| Bi | 2.6 | 4.1E2 | N | 0.006 |  |  |  |  |  | .167 |  |
| Pb | 320 |  |  |  |  |  |  |  |  |  |  |
| Tl | < 8.3 | 1.5E2 | N | <.055/ |  |  |  |  |  | <1.535 |  |
| Au | < 4.1 | N | N |  |  |  |  |  |  |  |  |
| Ir | < 6.3 |  |  |  |  |  |  |  |  |  |  |
| Os | < 7.0 |  |  |  |  |  |  |  |  |  |  |
| Re | < 4.5 |  |  |  |  |  |  |  |  |  |  |
| W | 6.2-33 | 1.0E3 | N | .006-.033 |  |  |  |  |  | < .921 |  |
| Hf | <13 |  |  |  |  |  |  |  |  |  |  |
| Lv | < 3 |  |  |  |  |  |  |  |  |  |  |
| Yb | < 3.2 |  |  |  |  |  |  |  |  |  |  |
| Tm | < 2.5 |  |  |  |  |  |  |  |  |  |  |

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a < 2032

ECOLOGICAL MATE BASED (Σ COL. G) 5b 470

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 30

ECOLOGICAL 6b 1

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a < 56,700

ECOLOGICAL MATE BASED (Σ COL. L) 7b 13,113

(ENTER HERE AND AT LINE 8, FORM IA01)

## TABLE 33 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 2

SOURCE/CONTROL OPTION Conventional Lignite Boiler With Multiclone

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ if HEALTH MATE EXCEEDED | √ if ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | ug/m$^3$ | ug/m$^3$ | | — | — | — | — | — | — | | |
| Er | < 4.8 | | | | | | | | | | |
| Ho | < 1.1 | | | | | | | | | | |
| Dy | < 3.2 | 9.3E3 | N | .0003 | | | | | | < .008 | |
| Tb | < 0.7 | | | | | | | | | | |
| Gd | < 3.2 | | | | | | | | | | |
| Eu | < 1.8 | | | | | | | | | | |
| Sm | < 5.4 | 5.3E4 | N | <.0001 | | | | | | < .003 | |
| Nd | 13 | N | N | | | | | | | | |
| Pr | 29 | 5.1E4 | N | .0006 | | | | | | .017 | |
| Ce | 240 | 3.7E4 | N | .0065 | | | | | | .181 | |
| La | 320 | 1.1E5 | N | .0029 | | | | | | .081 | |
| Ba | 200,000 | 5.0E2 | N | 400 | | | | | | 11,160 | |
| Cs | 18 | | | | | | | | | | |
| I | 3.3 | | | | | | | | | | |
| Te | < 3.3 | 1.0E2 | N | <.033 | | | | | | < .921 | |
| Sb | 40 | 5.0E2 | N | .08 | | | | | | 2.232 | |
| Sn | 23 | N | N | | | | | | | | |
| Cd | 33 | 1.0E1 | N | 3.3 | | | | | | 92.07 | |
| Pd | < 6.7 | | | | | | | | | | |
| Rh | 6.6 | | | | | | | | | | |
| Ru | < 3.6 | | | | | | | | | | |
| Mo | 38 | 5.0E3 | N | .0076 | | | | | | 0.212 | |
| Nb | 67 | | | | | | | | | | |
| Zr | 1300 | | | | | | | | | | |
| Y | 190 | | | | | | | | | | |
| Sr | 41,000 | 3.1E3 | N | 13.23 | | | | ✓ | | 369.1 | |

## TABLE 33 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 3

SOURCE CONTROL OPTION Conventional Lignite Boiler With Multiclone

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | TOXIC UNIT DISCHARGE RATE | |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | | | | — | — | — | — | — | — | | |
| Rb | 290 | | | | | | | | | | |
| Br | 210 | | | | | | | | | | |
| Se | 83 | 2.0E2 | N | .415 | | | | ✓ | | 11.58 | |
| As | 1,600 | 2.0 | N | 800 | | | | | | 22,320 | |
| Ge | 7.2 | 5.6E2 | N | .0129 | | | | | | .360 | |
| Ga | 240 | 5.0E3 | N | .048 | | | | | | 1.34 | |
| Zn | 880 | 4.0E3 | N | .220 | | | | | | 6.138 | |
| Cu | 470 | 2.0E2 | N | 2.35 | | | | ✓ | | 65.57 | |
| Ni | 1,400 | 1.5E1 | N | 93.33 | | | | ✓ | | 2604 | |
| Co | 100 | 5.0E1 | N | 2.0 | | | | ✓ | | 55.8 | |
| Fe | --- | | | | | | | | | | |
| Mn | 27,000 | 5.0E3 | N | 5.4 | | | | ✓ | | 150.7 | |
| Cr | 470 | 1 | N | 470 | | | | ✓ | | 13,113 | |
| V | 470 | 5.0E2 | 1 | .94 | | 470 | | | | 26.23 | 13,113 |
| Ti | 28,000 | 6.0E3 | N | 4.67 | | | | ✓ | | 130.3 | |
| Ca | --- | | | | | | | | | | |
| K | 39,000 | N | N | | | | | | | | |
| S | 160,000 | | | | | | | | | | |
| P | 16,000 | 1.0E2 | N | 160 | | | | ✓ | | 4,464 | |
| Si | --- | 1.0E4 | N | | | | | | | | |
| Al | --- | 5.2E3 | N | | | | | | | | |
| Mg | --- | 6.0E3 | N | | | | | | | | |
| Na | --- | 5.3E4 | N | | | | | | | | |
| B | 140,000 | 3.1E3 | N | 45.16 | | | | ✓ | | 1,260 | |
| Be | 10 | 2.0 | N | 5.0 | | | | ✓ | | 139.5 | |
| Li | 570 | 2.2E1 | N | 25.91 | | | | ✓ | | 722.9 | |

greater ambient hazard than the emissions from Site A. This indicates that the gasifier cyclones and boiler cyclone in use at ERCA have a combined performance at least equal to the multiclones in use at Site A.

Site B is a lignite-fired conventional power plant boiler using an ESP for particulate control. The measured emission at the stack is 0.0012 gm/m$^3$, a factor of 2000 less than the total particulate emissions indicated by the two SASS runs at the ESSO pilot plant. Table 34 indicates the results of the SAM/IA analysis of trace element emissions from this site. The only elements with hazard factors greater than 1 are arsenic, nickel, chromium, and vanadium (ecology); and these values are all reported as upper limits. The accuracy of the SSMS analysis in this case is quite low because of the very small amount of material collected in the sampling train. The data are presented to demonstrate the capability of an available control device to lower trace element emissions to acceptable levels.

A summary of trace element emission data representing the two conventional sites and the ESSO pilot plant is presented in Table 35. All elements with hazard factors > 1 at any of the three sites are included. In addition, some other trace elements (namely, Pb, Sb, Zr, Br, Zn) and sulfur are included for the purpose of discussion. Lignite trace element concentrations are presented to indicate comparative amounts processed by each of the three systems. One immediately apparent feature is that the trace element emissions measured at the CAFB and Site A are very similar, considering the accuracy of the SSMS analysis technique. This seems to be true regardless of the input quantity of each trace element. The most striking differences in feed quantities between CAFB and Site A exist for the elements Zr, Cr, V, Ti, Mg, Be, and Co. The feed concentration to the CAFB is at least an order of magnitude higher than the feed concentration at Site A for these six elements. However, the flue gas emissions of these elements are all higher at Site A than the CAFB, except for beryllium. This is partially explained by the fact that total particulate emissions at Site A are higher than at the ESSO pilot plant by a factor of 3.4 (8.5 gm/m$^3$ versus 2.5 gm/m$^3$). This being the case, there must be some factor that explains why emissions of these elements from the CAFB pilot plant are generally lower than measured at Site A by a factor of about 1.5 to 2 instead of being higher by a factor of > 10/3.4. Apparently, as noted for residual oil gasification, there is significant adsorption of these trace elements by the bed material. Trace elements may also be retained in the system in association with nonelutriated ash particles.

Trace element emission concentrations noted for Site B, where an ESP is used for final particulate control, are generally about two orders of magnitude less than emissions from the pilot plant and Site A. Since trace element feed concentrations are similar for Sites A and B, it is projected that application of a high efficiency control device at a commercial CAFB installation would provide very adequate control of trace element emissions.

TABLE 34. SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

**SAM/IA WORKSHEET FOR LEVEL 1** **Form IA02 Level 1**

1. SOURCE/CONTROL OPTION Page 1

Conventional Lignite Boiler With ESP - Site B

2. EFFLUENT STREAM

101 (CODE #) Flue Gas (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 40.5 m$^3$/sec

(gas = m$^3$/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | TOXIC UNIT DISCHARGE RATE |  |
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | ✓ IF HEALTH MATE EXCEEDED | ✓ IF ECOL MATE EXCEEDED | (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS |  |  |  | — | — | — | — | — | — |  |  |
| U | < 1.2 |  |  |  |  |  |  |  |  |  |  |
| Th | < 1.7 |  |  |  |  |  |  |  |  |  |  |
| Bi | < .5 | 4.1E2 | N | <.0012 |  |  |  |  |  | <.049 |  |
| Pb | 1.1 - 8.5 |  |  |  |  |  |  |  |  |  |  |
| Tl | < .7 | 1.5E2 | N | <.0047 |  |  |  |  |  | <.190 |  |
| Au | < .9 | N | N |  |  |  |  |  |  |  |  |
| Ir | < 1.4 |  |  |  |  |  |  |  |  |  |  |
| Os | < 1.5 |  |  |  |  |  |  |  |  |  |  |
| Re | < .9 |  |  |  |  |  |  |  |  |  |  |
| W | < 1.3 | 1.0E3 | N | <.0013 |  |  |  |  |  | <.053 |  |
| Hf | < 1.6 |  |  |  |  |  |  |  |  |  |  |
| Lv | < .4 |  |  |  |  |  |  |  |  |  |  |
| Yb | < .5 |  |  |  |  |  |  |  |  |  |  |
| Tm | < .3 |  |  |  |  |  |  |  |  |  |  |

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD
HEALTH MATE BASED (Σ COL. E) 5a < 12.1
ECOLOGICAL MATE BASED (Σ COL. G) 5b < 1.1
(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES
HEALTH 6a 34
ECOLOGICAL 6b 1

7. TOXIC UNIT DISCHARGE SUM
HEALTH MATE BASED (Σ COL. K) 7a < 490.8
ECOLOGICAL MATE BASED (Σ COL. L) 7b < 44.55
(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE 34 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

**CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02, LEVEL 1**

Page 2

SOURCE/CONTROL OPTION Conventional Lignite Boiler With ESP

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3) | TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | | | | — | — | — | — | — | — | | |
| Er | < 1 | | | | | | | | | | |
| Ho | < .3 | | | | | | | | | | |
| Dy | < .5 | 9.3E3 | N | .00005 | | | | | | .002 | |
| Tr | < .1 | | | | | | | | | | |
| Gd | < .5 | | | | | | | | | | |
| Ev | < .2 | | | | | | | | | | |
| Sm | < .9 | 5.3E4 | N | .00002 | | | | | | .001 | |
| Nd | < 1.2 | N | N | | | | | | | | |
| Pr | < .2 | 5.1E4 | N | <.00001 | | | | | | < .0004 | |
| Ce | < .3 | 3.7E4 | N | <.00001 | | | | | | < .0004 | |
| La | < .3 | 1.1E5 | N | <.00001 | | | | | | < .0004 | |
| Ba | < 28 | 5.0E2 | N | .056 | | | | | | <2.268 | |
| Cs | < .1 | | | | | | | | | | |
| I | < .8 | | | | | | | | | | |
| Te | < .7 | 1.0E2 | N | <.007 | | | | | | < .284 | |
| Sb | < .5 | 5.0E2 | N | <.001 | | | | | | < .041 | |
| Sn | 1.3-16 | N | N | | | | | | | | |
| Cd | .9-2.1 | 1.0E1 | N | .09-.21 | | | | | | <8.505 | |
| Pd | < .7 | | | | | | | | | | |
| Rh | < .2 | | | | | | | | | | |
| Ru | < .9 | | | | | | | | | | |
| Mo | .8 | 5.0E3 | N | .0002 | | | | | | .008 | |
| Nb | < .1 | | | | | | | | | | |
| Zr | .3 | | | | | | | | | | |
| Y | < .1-.1 | | | | | | | | | | |
| Sr | <10 | 3.1E3 | N | <.0032 | | | | | | < .130 | |

TABLE 34 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1

Page 3

SOURCE/CONTROL OPTION Conventional Lignite Boiler With ESP

EFFLUENT STREAM NO 101

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE FRACTION | FRACTION CONCENTRATION | HEALTH MATE CONCENTRATION | ECOLOGICAL MATE CONCENTRATION | DEGREE OF HAZARD (HEALTH) (B/C) | ORDINAL POSITION IN HEALTH MATE TABLE | DEGREE OF HAZARD (ECOLOGICAL) (B/D) | ORDINAL POSITION IN ECOL MATE TABLE | √ IF HEALTH MATE EXCEEDED | √ IF ECOL MATE EXCEEDED | TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3) | (ECOLOGICAL BASED) (G x LINE 3) |
| UNITS | | | | — | — | — | — | — | — | | |
| Rb | < .1-.4 | | | | | | | | | | |
| Br | < 43 | | | | | | | | | | |
| Se | 9.7 | 2.0E2 | N | .0485 | | | | | | 1.964 | |
| As | < 4.2 | 2.0 | N | < 2.1 | | | | ✓ | | < 85.05 | |
| Ge | < .1-.3 | 5.6E2 | N | <.0005 | | | | | | < .02 | |
| Ga | < .1-.1 | 5.0E3 | N | <.00002 | | | | | | < .001 | |
| Zn | 13-31 | 4.0E3 | N | <.0078 | | | | | | < .316 | |
| Cu | < 36 | 2.0E2 | N | <.18 | | | | | | < 7.29 | |
| Ni | < 69 | 1.5E1 | N | < 4.6 | | | | ✓ | | < 186.6 | |
| Co | < .8 | 5.0E1 | N | <.016 | | | | | | < .648 | |
| Fe | <170 | | | | | | | | | | |
| Mn | < 7.8 | 5.0E3 | N | <.0016 | | | | | | < .065 | |
| Cr | < 4.2 | 1 | N | <4.2 | | | | ✓ | | <170.1 | |
| V | < 1.1 | 5.0E2 | 1 | <.0022 | | 1.1 | | | ✓ | < .089 | < 44.55 |
| Ti | < 3.5 | 6.0E3 | N | <.0006 | | | | | | < .024 | |
| Ca | 40-390 | | | | | | | | | | |
| K | 560 | N | N | | | | | | | | |
| S | 1400-7700 | | | | | | | | | | |
| P | < 46 | 1.0E2 | N | <.46 | | | | | | < 18.63 | |
| Si | 180 | 1.0E4 | N | .0180 | | | | | | .729 | |
| Al | 36-88 | 5.2E3 | N | <.0169 | | | | | | < .684 | |
| Mg | 160 | 6.0E3 | N | .0267 | | | | | | 1.081 | |
| Na | 680 | 5.3E4 | N | .0128 | | | | | | .518 | |
| B | 64 | 3.1E3 | N | .0206 | | | | | | .834 | |
| Be | .2 | 2.0 | N | .1 | | | | | | 4.05 | |
| Li | < .3 | 2.2E1 | N | .0136 | | | | | | .551 | |

## TABLE 35. SUMMARY OF TRACE ELEMENT DATA

| Trace element | Lignite fuel feed data (ppm) |  |  | Flue gas emissions ($\mu g/m^3$) |  |  |  | Solid basis (ppm) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | CAFB 1197 | Site A | Site B | CAFB |  | Site A | Site B | CAFB |  | Site A |
|  |  |  |  | SASS-1 | SASS-2 |  |  | SASS-1 | SASS-2 |  |
| Pb | 9.6 | 1.7 | 2.3 | 200 | 310 | 320 | 1.1 to 8.5 | 90.5 | 113 | 37.7 |
| Ba | 38 | 110 | 7.0 | 2,800 | 5,100 | 200,000 | <28 | 1,268 | 1,018 | 23,585 |
| Sb | 0.30 | 0.055 | <0.22 | 7.2 | 18 | 40 | < 0.5 | 3.3 | 2.6 | 4.7 |
| Cd | 0.17 | 0.28 | <0.39 | 5.4 | 15 | 33 | 0.9 to 2.1 | 2.4 | 2.0 | 3.9 |
| Zr | 5.9 | 0.37 | 0.35 | 510 | 540 | 1,300 | 0.3 | 231 | 196 | 153 |
| Sr | 37 | 38 | 46 | 2,600 | 5,000 | 41,000 | <10 | 1,177 | 1,818 | 4,835 |
| Br | 0.23 | 3.3 | 3.2 | 160 | 190 | 210 | <43 | 72.4 | 69.1 | 24.8 |
| As | 1.5 | 2.6 | 0.48 | 650 | 1,000 | 1,600 | < 4.2 | 294 | 364 | 189 |
| Zn | 13 | 10 | 15.0 | 860 | 1,900 | 880 | 13 to 31 | 389 | 691 | 104 |
| Cu | 15 | 62 | 7.1 | 180 | 260 | 470 | <36 | 81.5 | 94.6 | 55.4 |
| Ni | 23 | 4 | 48 | 230 | 380 | 1,400 | <69 | 104 | 138 | 165 |
| Cr | 2.7 | 0.48 | 0.61 | 110 | 330 | 470 | < 4.2 | 49.8 | 120 | 55.4 |
| V | 14 | 0.56 | 0.87 | 310 | 430 | 470 | < 1.1 | 140 | 156 | 55.4 |
| Ti | 230 | 9.3 | 15.0 | 13,000 | 14,000 | 28,000 | < 3.5 | 5,885 | 5,091 | 3,302 |
| S | 0.23% | 0.23% | 1.4% | - | 220,000 | 160,000 | 1400 to 7700 | - | 80,000 | 18,868 |
| P | 42 | 14 | 8.6 | 1,600 | 1,600 | 16,000 | <46 | 724 | 582 | 1,887 |
| Si | MC | 170 | 420 | 230,000 | - | - | 180 | 104,100 | - | - |
| Mg | 130% | 420 | 840 | 16,000 | 15,000 | MC | 160 | 7,243 | 5,455 | - |
| B | 21 | 6.3 | 8.9 | 4,300 | 3,100 | 140,000 | 64 | 1,946 | 1,127 | 16,509 |
| Be | 0.03 | 0.018 | 0.037 | 14 | 3.8 | 10 | 0.2 | 6.3 | 1.4 | 1.2 |
| Li | 0.82 | 0.26 |  | ND | 60 | 570 | <0.3 |  | 21.8 | 67.2 |
| Co | 0.50 | 0.089 | 0.17 | 48 | 44 | 100 | <0.8 |  |  |  |
| Mn | 22 | 11.0 | 13.0 | 1,700 | 2,000 | 27,000 | <7.8 |  |  |  |

Note: ND = not determined; MC = major component.

## ORGANIC EMISSIONS

The variability of the distribution of organic emissions among the gaseous, volatile and condensable samples collected during the two SASS and two Tenax RAC runs is demonstrated by the emissions summary presented in Table 36. As noted in Section 4, SASS No. 1 measurements were made during reinjection of gasifier fines with the apparent result that lignite gasification efficiency was higher than during subsequent runs.

To establish a basis for evaluation of the potential environmental impact of organic emissions from the CAFB, Table 37 summarizes emissions determined by GCA from six conventional lignite-fired boilers. Comparison between the data in Tables 36 and 37 shows that the total organic emissions from the CAFB fall in the middle of the range found for conventional systems. The > $C_6$ emissions from the CAFB during SASS No. 1 is on the low end of the distribution, while the emissions from SASS No. 2 and RAC No. 4 are higher than any found from conventional systems.

The principal conclusions which can be drawn from a comparison between CAFB and conventional organic emissions is that when operated efficiently, gaseous ($C_1$ - $C_6$) organic emissions from the CAFB are equivalent to those from conventional systems and emissions of heavier organics are lower than the average from conventional boilers. The large number of organic functional groups identified by infrared spectroscopy indicates that Level II organic analyses should be performed to definitize the specific compound nature of the organic emissions.

TABLE 36. TOTAL CAFB ORGANIC EMISSIONS ($\mu g/m^3$)

| | SASS No. 1 | SASS No. 2 | RAC No. 2 | RAC No. 4 |
|---|---|---|---|---|
| $C_1$ - $C_6$ | 17,770-<br>23,192 | No data | 4,337-<br>10,384 | < 6,380 |
| $C_7$ - $C_{16}$ | 221 | 307 | 650* | 1,430* |
| > $C_{16}$ | 565 | 21,725 | 7,590* | 19,740* |
| Total | 18,556-<br>23,978 | > 21,725 | 12,577-<br>18,624 | 21,170-<br>27,550 |

*Average RAC 1-5 particulate emissions plus Tenax captured emissions.

TABLE 37. ORGANIC EMISSIONS FROM CONVENTIONAL LIGNITE-FIRED UTILITY BOILERS

| Boiler type | Organic emissions (µg/m³) | | | Total organic emissions (µg/m³) |
|---|---|---|---|---|
| | $C_1 - C_6$ | $C_7 - C_{16}$ | $> C_{16}$ | |
| Pulverized dry bottom (front fired) | 39,020-44,520 | 434 | 9,800 | 49,300-54,800 |
| Pulverized dry bottom (front fired) | 5,340-17,430 | 936 | 6,930 | 13,200-25,300 |
| Pulverized dry bottom (front fired) | 4,000-13,000 | 558 | 64 | 4,600-13,600 |
| Cyclone | 10,680-22,770 | 382 | 2,410 | 13,500-25,600 |
| Spreader stoker | 1,780-13,870 | 643 | 1,745 | 4,200-16,300 |
| Spreader stoker | No data | 27 | 332 | > 359 |

## EMISSIONS FROM OIL-FIRED HDS AND FGD PROCESSES

Potential emissions from these sources have been discussed in an earlier report.[3] Pollutant streams emanating from limestone FGD and Flexicoking HDS will be specified here.

### Limestone FGD

This is a "throwaway" FGD method which uses a circulating $CaCO_3$ scrubbing solution for $SO_2$ removal by the following reactions:[4]

$$CaCO_3 + SO_2 + \frac{1}{2} H_2O \rightarrow CaSO_3 \cdot \frac{1}{2} H_2O + CO_2$$

$$CaSO_3 \cdot \frac{1}{2} H_2O + 3/2\ H_2O + \frac{1}{2} O_2 \rightarrow 2\ H_2O +$$

The calcium sulfite/sulfate solid waste generated amounts to approximately four times the weight of sulfur removed from the flue gas stream.[5] The waste slurry is generally discharged to a large pond for solids separation or it can be dewatered by mechanical means such as centrifugation or filtration. The chemical pollutants in FGD sludges originate from process ingredients, fuel, combustion products, absorbents, and process makeup water. Trace elements exist in the slurry liquor in the range of 0.01 to 1.0 mg/ℓ and in the solid phase at a concentration approximately two orders of magnitude higher.[6] (See Table 38.) The limestone scrubbing system operates at the lowest pH in comparison to other FGD systems and, therefore, has the highest distribution of trace elements in liquor. Typically, trace element distribution will be 1 to 2 percent in liquid and 98 to 99 percent in the solids. The low pH in the limestone process apparently causes a greater degree of trace element leaching from the fly ash. Table 39 illustrates the chemical characteristics of limestone FGD solids at a number of coal-fired plants.

It is reported that the most persistent pollution potential associated with limestone FGD waste disposal is by water percolation through the sludge and subsoil into the subterranean water table. Three methods of reducing the environmental impact of limestone FGD waste disposal are:[4]

- decreasing the permeability of solid wastes to reduce water seepage
- reducing leachability through a reduction of solubility
- managing seepage and runoff to limit the excess of waste constituents to ground-water or surface-water

An effective embodiment of these ideas is sluicing of waste sludge to an underdrained pond so that excess liquor can be returned to the scrubber while reducing seepage and overflow by minimizing supernatant hydraulic head.[6]

TABLE 38. RANGE OF CONCENTRATIONS OF CHEMICAL CONSTITUENTS IN FGD SLUDGES

| Scrubber constituent | Sludge concentration range | |
|---|---|---|
| | Liquor (mg/ℓ, except pH)[*] | Solid (ppm)[†] |
| Aluminum | 0.03 - 2.0 | - - |
| Arsenic | <0.004 - 1.8 | 0.6 - 52 |
| Beryllium | <0.002 - 0.18 | 0.05 - 6 |
| Cadmium | 0.004 - 0.11 | 0.08 - 4 |
| Calcium | 180 - 2600 | 105,000 - 268,000 |
| Chromium | 0.015 - 0.5 | 10 - 250 |
| Copper | <0.002 - 0.56 | 8 - 76 |
| Lead | 0.01 - 0.52 | 0.23 - 21 |
| Magnesium | 4.0 - 2750 | - - |
| Mercury | 0.0004 - 0.07 | 0.001 - 5 |
| Potassium | 5.9 - 100 | - - |
| Selenium | <0.0006 - 2.7 | 2 - 17 |
| Sodium | 10.0 - 29,000 | - - (4.8) |
| Zinc | 0.01 - 0.59 | 45 - 430 |
| Chloride | 420 - 33,000 | - - (0.9) |
| Fluoride | 0.6 - 58 | - - |
| Sulfate | 600 - 35,000 | 35,000 - 473,000 |
| Sulfite | 0.9 - 3500 | 1600 - 302,000 |
| Chemical oxygen demand | <1 - 390 | - - |
| Total dissolved solids | 2800 - 92,500 | - - |
| pH | 4.3 - 12.7 | |

---

[*] Liquor analyses were conducted on 13 samples from seven power plants burning eastern or western coal and using lime, limestone, or double-alkali absorbents.

[†] Solids analyses were conducted on six samples from six power plants burning eastern or western coal and using lime, limestone, or double alkali.

TABLE 39. PHASE COMPOSITION OF FGD WASTE SOLIDS IN WEIGHT PERCENT[6]

| Atomic formula | TVA Shawnee limestone, 2/1/73 | TVA Shawnee limestone, 7/12/73 | TVA Shawnee limestone, 6/15/74 | SCE Mohave limestone, 3/30/73 | APS Cholla limestone, 4/1/74 |
|---|---|---|---|---|---|
| $CaSO_4 \cdot 2H_2O$ | 21.9 | 15.4 | 31.2 | 84.6 | 17.3 |
| $CaSO_3 \cdot 1/2H_2O$ | 18.5 | 21.4 | 21.8 | 8.0 | 10.8 |
| $CaCO_3$ | 38.7 | 20.2 | 4.5 | 6.3 | 2.5 |
| $MgSO_4 \cdot 6H_2O$ | 4.6 | 3.7 | 1.9 | - | - |
| NaCl | - | - | - | 1.5 | - |
| Fly ash | 20.1 | 40.9 | 40.1 | 3.0 | 58.7 |
| Total | 103.8 | 101.6 | 99.5 | 103.4 | 89.3 |

## Flexicoking

This process was developed by EXXON Research and Engineering Company as a method of producing low sulfur fuel oil blendstocks from a wide range of residual feedstocks.[3] A schematic process diagram is shown in Figure 21.[8] The major pollutant sources include the purge coke, the venturi scrubber and cyclones fines, and the fractionator wastewater. Minor fugitive emissions may escape from equipment and piping joints. The coke purge quantity ranges between 1 and 2 percent of the total feed weight. Approximately 99 percent of the trace metals in the feedstock are concentrated in the coke purge, cyclone fines and venturi scrubber fines.[7] Table 40 illustrates the chemical characteristics of these three streams during processing of West Texas sour asphalt, and documents the system's capability for trace metal removal.[8] Table 41 shows a materials balance for vanadium based on a feedstock concentration of 160 ppm.[7]

The Flexicoking system is also efficient in generating a coke gas with low nitrogen content typically less than 3 ppm. This minimizes the formation of nitrogen compounds during combustion of the product gas.

Fractionator scrubber wastewater is the major source of liquid waste within the Flexicoking process. In general, this stream will contain organics, solids, trace elements, and sulfur compounds. A recent publication[8] indicates that conventional biological treatment or some form of activated carbon filtration would be suitable for producing a water stream with effluent quality within the limits of current regulations.

Fugitive leakage at pipe joints or other equipment connections would discharge a minor quantity of hydrocarbon compounds.

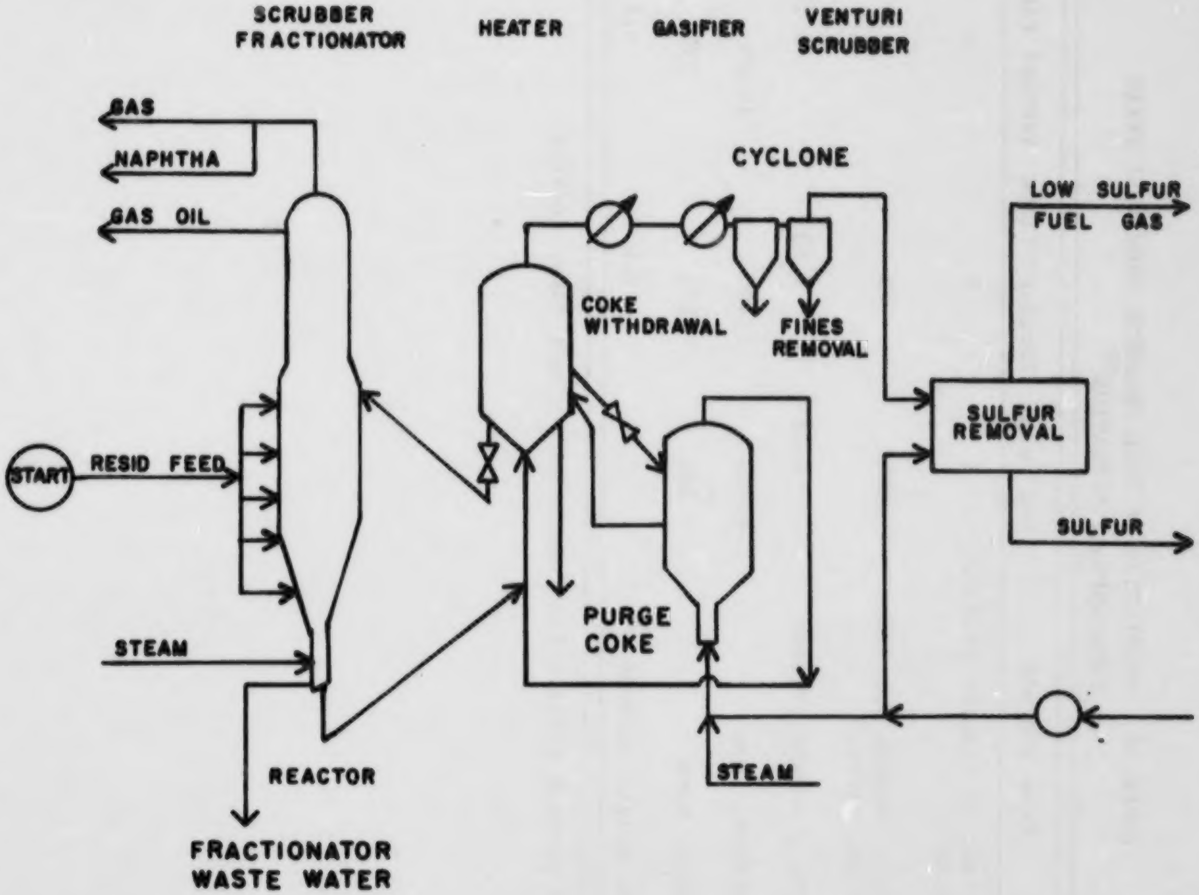
SCRUBBER FRACTIONATOR
HEATER
GASIFIER
VENTURI SCRUBBER
GAS
NAPHTHA
GAS OIL
CYCLONE
LOW SULFUR FUEL GAS
COKE WITHDRAWAL
FINES REMOVAL
SULFUR REMOVAL
START
RESID FEED
SULFUR
PURGE COKE
STEAM
STEAM
REACTOR
FRACTIONATOR WASTE WATER

Figure 21. Flexicoking Unit.[8]

TABLE 40. PROPERTIES OF COKE PRODUCTS FROM WEST TEXAS SOUR ASPHALT OPERATION*[6]

| Coke product | Bed purge | Tertiary fines | Venturi fines |
|---|---|---|---|
| Percent of reactor product coke | 1 | 2 | 2 |
| Weight average particle size, microns | 105 | 25 | 5 |
| Sulfur, weight percent | 2.08 | 2.60 | 3.15 |
| Vanadium, wppm | 4,990 | 5,400 | 10,800 |
| Nickel, wppm | 380 | 295 | 590 |
| Ash, weight percent | 2.0 | 2.6 | 5.2 |

*95 percent gasification operation without fines recycle.

TABLE 41. PROTOTYPE FLEXICOKER DISPOSITION OF VANADIUM AMONG PRODUCTS*

| | Vanadium concentration (wppm) | Vanadium rate (lbs/day) | Percent of feed vanadium |
|---|---|---|---|
| Fresh feed | 160 | 37 | 100 |
| Reactor liquid product | - | 0.5 | 1.3 |
| Bed coke purge | 5,800 | 6.1 | 16.5 |
| Tertiary cyclone fines | 9,000 | 14.0 | 37.8 |
| Venturi scrubber fines | 11,000 | 18.7 | 50.5 |
| Total output | | 39.3 | 106.1† |

*Vanadium balance obtained during the West Texas resid/asphalt operation.

†Percent of feed vanadium as total output indicative of vanadium balance closure.

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4. Engdahl, R. B., J. M. Genco, and H. S. Rosenberg. State of the Art for $SO_2$ Control for Coal-Fired Power Plants. Battelle Memorial Institute.

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7. Matula, J. P., B. V. Molstedt, and D. F. Ryan. Flexicoker Prototype Demonstrates Successful Operation. EXXON Research and Engineering Company. 40th Midyear Meeting of the Division of Refining, American Petroleum Institute. May 13, 1975.

8. Griffel, J., G. E. Phillips, and G. C. Spry. Flexicoking Clean Products from Dirty Fuels. EXXON Research and Engineering Company. May 13, 1976.

# APPENDIX A

## PROCESS DESCRIPTIONS AND ECONOMICS OF RESIDUAL OIL DESULFURIZATION TECHNIQUES

Several refinery processes exist for the desulfurization of fuel feedstock. A number of these systems have been discussed in an earlier report, and include the following:[1]

- Flexicoking
- Gulf HDS
- RCD Isomax
- Residue Desulfurization (BP)
- Resid Hydroprocessing (Standard Oil)
- LC Fining
- Resid Ultrafining
- Go Fining
- Residfining
- Residue Hydrodesulfurization
- Hydrodesulfurization, Trickle Flow
- IFP Resid and VGO Hydrodesulfurization
- Demetallization/Desulfurization
- Delayed Coking
- VGO/VRDS Isomax
- Shell Gasification

The purpose of this discussion is to update the technical and economic information which was presented for these processes and to report upon new processes which have been identified since the initial study. These additional processes include:

- Autofining
- Gulfining
- Shell Residual Oil Hydrodesulfurization
- Exxon Hydrofining
- BP Hydrofining
- Ultrafining
- Unicracking/HDS
- Unionfining

Literature review and correspondence with developers have indicated that technical modifications instituted since the initial report[1] have little economic impact. The major point of technical advance seems to be catalyst improvement, which enhances demetallization and desulfurization, extends catalyst life, and reduces catalyst replacement cost.

## THE GENERAL HYDRODESULFURIZATION PROCESS

The hydrodesulfurization process is used to remove sulfur, nitrogen and metals from petroleum feedstocks. In most cases, the feedstock is mixed with hydrogen-rich gas, preheated, and sent to a fixed bed reactor where the mixture comes into contact with a cobalt or nickel-molybdenum catalyst. Fuel sulfur is converted to $H_2S$, nitrogen to $NH_3$, and metals are picked up by the catalyst. The reactor products are cooled and travel to a separator where $H_2S$ and hydrogen are removed. Hydrogen is recycled to the head of the process and $H_2S$ is treated further for sulfur recovery. The liquid product is steam-stripped to remove residual contaminants and may be fractionated depending upon the desired end products. A typical schematic process flow diagram appears in Figure A-1.

In some cases, an ebullating bed or continuous catalyst feed and withdrawal system is used. The design and operation of each system is dependent upon the feedstock and desired end products.

## ECONOMIC FORECAST

In order to develop a basis of cost comparison among the various hydrodesulfurization processes, all economic data has been forecasted to the year 1980. Published capital and operating costs were updated by use of the Nelson Refinery Inflation Index and the Nelson Refinery Operating Index. In addition, 1980 unit operating costs were estimated by reference to literature concerning refinery processes.[2-4] The 1980 Nelson Refinery Index values and the unit operating costs used for the analysis are as follows:

| | |
|---|---|
| • Nelson Refinery Inflation Index | 760 |
| • Nelson Refinery Operating Index | 295 |

1980 Unit Operating Costs:

| | |
|---|---|
| • Electricity | $0.03/kWh |
| • Supplemental fuel | $3.25/MMBtu |
| • Cooling water | $0.05/Mgal |
| • High pressure steam | $4.50/Mlbs |
| • Medium pressure steam | $3.25/Mlbs |
| • Low pressure steam | $2.00/Mlbs |
| • Process (boiler feed) water | $1.50/Mgal |
| • Hydrogen | $1.00/Mscf |

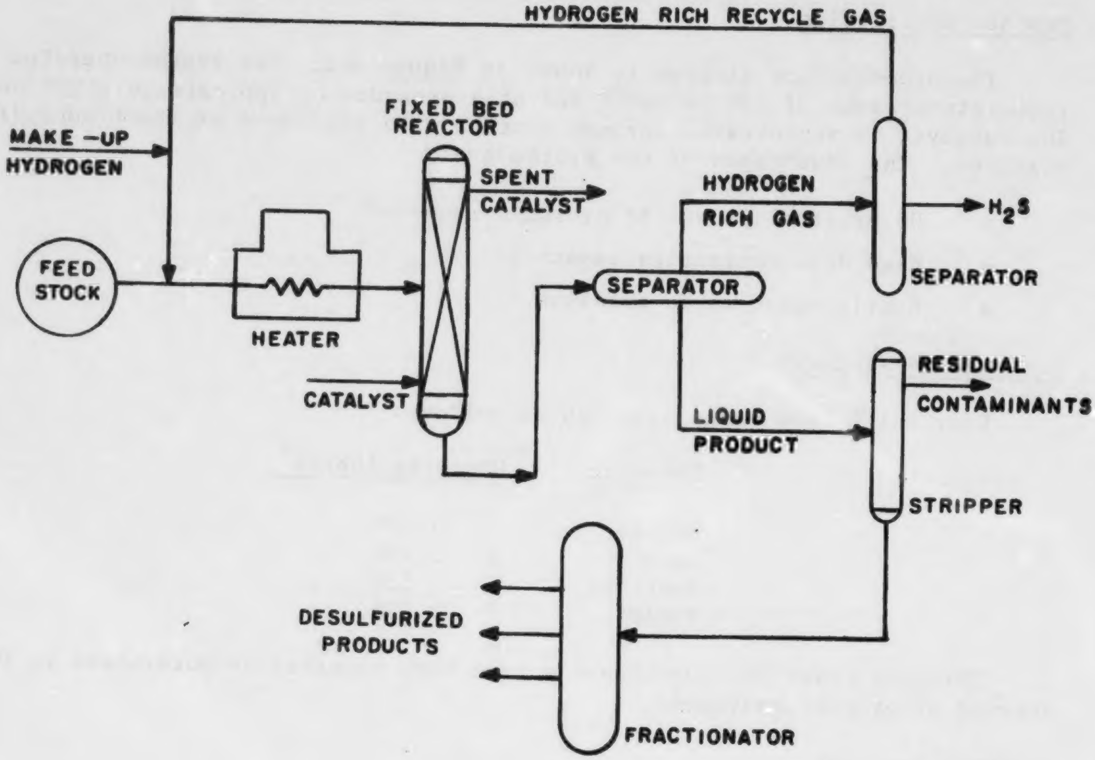
HYDROGEN RICH RECYCLE GAS
MAKE -UP HYDROGEN
FIXED BED REACTOR
SPENT CATALYST
HYDROGEN RICH GAS
$H_2S$
FEED STOCK
HEATER
SEPARATOR
SEPARATOR
CATALYST
RESIDUAL CONTAMINANTS
LIQUID PRODUCT
STRIPPER
DESULFURIZED PRODUCTS
FRACTIONATOR

Figure A-1. Generalized schematic hydrodesulfurization flow diagram.

These unit operating costs are identified here for use below, because, in most cases, actual utility requirements are published by licensors, rather than total operating costs for a given year. A discussion of the engineering and economic aspects of the newly identified residual oil desulfurization systems follows.

## AUTOFINING[5]

This process is licensed by British Petroleum Trading Limited and is used to desulfurize distillate stocks, such as feed to SNG plants, without an external source of hydrogen.

### Process Description

The process flow diagram is shown in Figure A-2. The system operates in the temperature range of 730 to 760°F and at a pressure of approximately 300 psig. The catalyst is regenerated through contact with air/steam or inert gas/air mixtures. The advantages of the system are:

- No external source of hydrogen required
- High desulfurization capacity
- Easily regenerable catalyst.

### Stage of Development

Four units have been installed as follows:

| Location | Capacity (bpsd)* |
|---|---|
| Wales | 3,500 |
| Aden | 3,500 |
| Scotland | 500 |
| France | 2,300 |

Thirteen other BP hydrotreaters have been operated as Autofiners in the absence of process hydrogen.

### Economic Forecast

The economic data given in Table A-1 are based on estimates for March 1976. The estimated 1980 investment cost was projected through the use of a Nelson Refinery Inflation Index of 760. Electricity and fuel costs were calculated based on estimated 1980 unit costs of \$0.03/kWh and \$3.25/MMBtu, respectively. The catalyst replacement cost was projected by use of a 1980 Nelson Refinery Operating Index of 295.

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*Barrels per stream day.

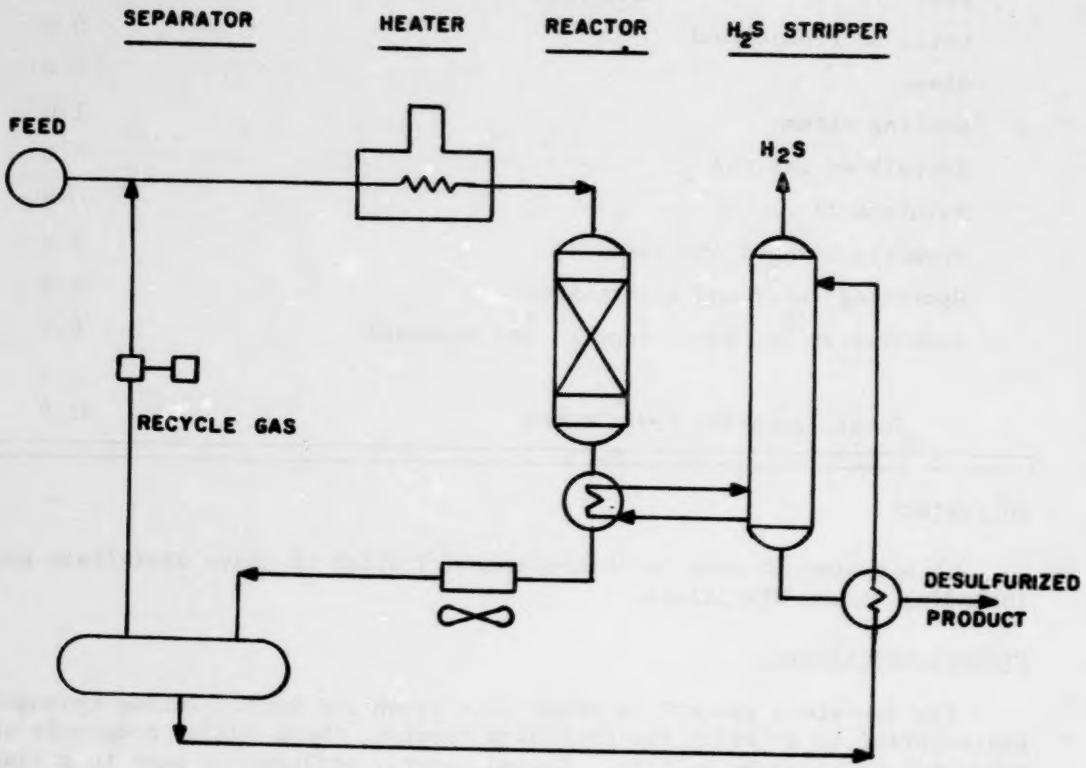
SEPARATOR
HEATER
REACTOR
$H_2S$ STRIPPER
FEED
$H_2S$
RECYCLE GAS
DESULFURIZED PRODUCT

Figure A-2. Autofining process.

TABLE A-1. ESTIMATED COST OF AUTOFINING, 1980

| | | Cost, $ per bpsd |
|---|---|---|
| Investment: | | |
| Basis: 45,000 bpsd unit, estimated erected cost, excluding initial catalyst charge. | | 95 |
| Operating Requirements, per bbl of feed | | Cost, ¢ per bbl feed |
| Electricity | 1.2 kWh | 3.6 |
| Fuel | 45.5 MBtu | 14.8 |
| Catalyst replacement | | 0.3 |
| Steam | | 2.0 |
| Cooling water | | 1.0 |
| Annualized capital | | 4.3 |
| Maintenance | | 0.9 |
| Property tax and insurance | | 0.6 |
| Operating labor and supervision | | 4.5 |
| Administration, misc. supply, and overhead | | 0.9 |
| Total operating cost, ¢/bbl | | 32.9 |

## GULFINING[6]

This system is used for hydrodesulfurization of heavy distillate gas oils including vacuum distillate.

### Process Description

The feedstock gas oil is mixed with fresh and recirculating hydrogen and heated prior to entering the Gulfining reactor, where sulfur compounds are converted to hydrogen sulfide. Cooled reactor effluent is sent to a flash drum where liquid oil is withdrawn from the bottom. High pressure flash drum liquid passes to the low pressure flash drum where hydrogen sulfide and additional fuel gas is flashed off. Liquid from the low pressure separator passes to the stripper tower where the desulfurized gas oil is stabilized. Figure A-3 shows the process diagram of the system.

Typical yields for Gulfining Middle East vacuum gas oil at 90 percent desulfurization are presented in Table A-2.

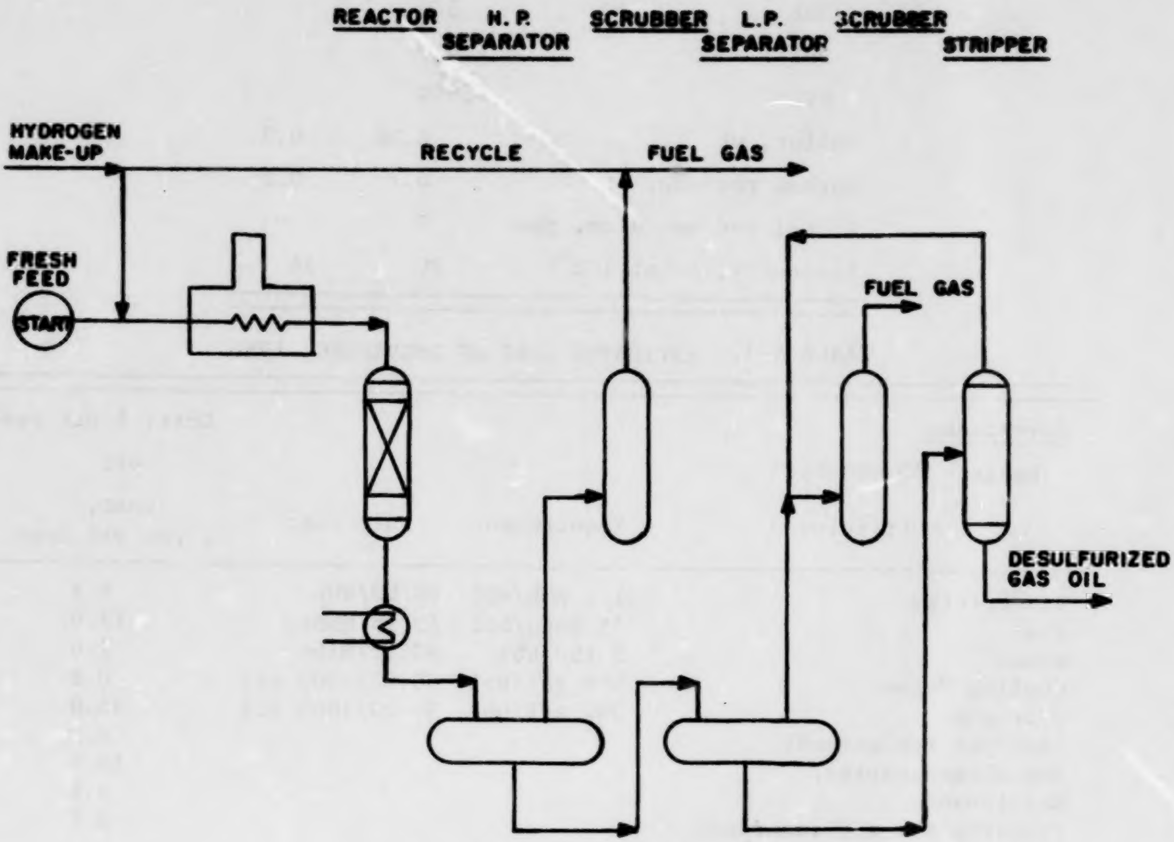
REACTOR
H. P. SEPARATOR
SCRUBBER
L.P. SEPARATOR
SCRUBBER
STRIPPER
HYDROGEN MAKE-UP
RECYCLE
FUEL GAS
FRESH FEED
START
FUEL GAS
DESULFURIZED GAS OIL

Figure A-3. Gulfining process.

## TABLE A-2. YIELDS FROM GULFINING PROCESS

| Characteristic | Feedstock | Product |
|---|---|---|
| Gravity, °API | 24.0 | 29.0 |
| ASTM Distillation, °F | | |
| 1 BP | 410 | |
| 10% | 622 | |
| 50% | 870 | |
| 90% | 1,020 | |
| EP | 1,090 | |
| Sulfur, wt. % | 2.20 | 0.2 |
| Carbon residue, wt. % | 0.7 | 0.2 |
| Nickel and vanadium, ppm | 2 | – |
| Viscosity, cs at 122°F | 20 | 16 |

## TABLE A-3. ESTIMATED COST OF GULFINING, 1980

| Investment | Cost, $ per bps |
|---|---|
| Basis: 35,000 bpsd | 416 |

| Utilities | Requirement | Unit Cost | Cost, ¢ per bbl feed |
|---|---|---|---|
| Electricity | 1.7 kWh/bbl | $0.03/kWh | 5.1 |
| Fuel | 55 MBtu/bbl | $3.25/MMBtu | 17.9 |
| Steam | 6 lbs/bbl | $3.25/Mlbs | 2.0 |
| Cooling Water | 160 gal/bbl | $0.05/1000 gal | 0.8 |
| Hydrogen | 350 scf/bbl | $1.00/1000 scf | 35.0 |
| Catalyst replacement | | | 0.3 |
| Annualized capital | | | 19.0 |
| Maintenance | | | 3.8 |
| Property tax and insurance | | | 2.6 |
| Operating labor and supervision | | | 3.5 |
| Administration, misc. supply, and overhead | | | 3.8 |
| Total operating cost, ¢/bbl | | | 93.8 |

### Economic Forecast

The economics of the Gulfining Process are illustrated in Table A-3 and are based on the operating parameters shown in Table A-2.

## HYDRODESULFURIZATION, RESIDUAL OIL (SHELL DEVELOPMENT CO.)[7]

The process is used to improve the quality of residual oils by removing sulfur, metals, and asphaltenes. Use of various catalysts makes the system capable of treating a wide range of feedstocks, including those which are high in metals and/or asphaltenes.

### Process Description

Feedstock is combined with hydrogen rich makeup and recycle gas and heated in heat exchangers and a furnace and then passes through the reactor in trickle flow. Reactor products are cooled and separated into a desulfurized product, a sour gas, and a hydrogen rich gas which is recirculated after $H_2S$ removal. A bunker reactor can be used for catalyst addition and withdrawal and is especially suited to treating high metals feedstocks. A process flow diagram appears in Figure A-4.

### Stage of Development

As of 1976, two units were in operation, one demonstration plant of 3,000 bpsd capacity and one commercial facility of 47,000 bpsd capacity.

### Economic Forecast

The economics of the process are based on the operating parameters shown in Table A-4.

TABLE A-4. TYPICAL OPERATING PARAMETERS SHELL RESIDUAL OIL HYDRODESULFURIZATION

| Properties | Feed (660°F+) | Product (330°F+) |
|---|---|---|
| Specific gravity, d 15/40°F | 0.967 | 0.917 |
| Viscosity, cs at 122°F | 580 | 61 |
| Sulfur, wt. % | 4.18 | 0.50 |
| Vanadium, ppm wt. | 50 | 12 |
| $C_7$ asphaltenes, % wt. | 2.5 | 1.2 |

Chemical $H_2$ consumption: 1.2% wt. on feed

Breakdown of products, % wt. on feed:

| | |
|---|---|
| $H_2S$ | 3.9 |
| $C_1$-$C_4$ | 0.9 |
| $C_5$-165°C | 1.0 |
| $165^{\circ}C^{+}$ | 95.4 |

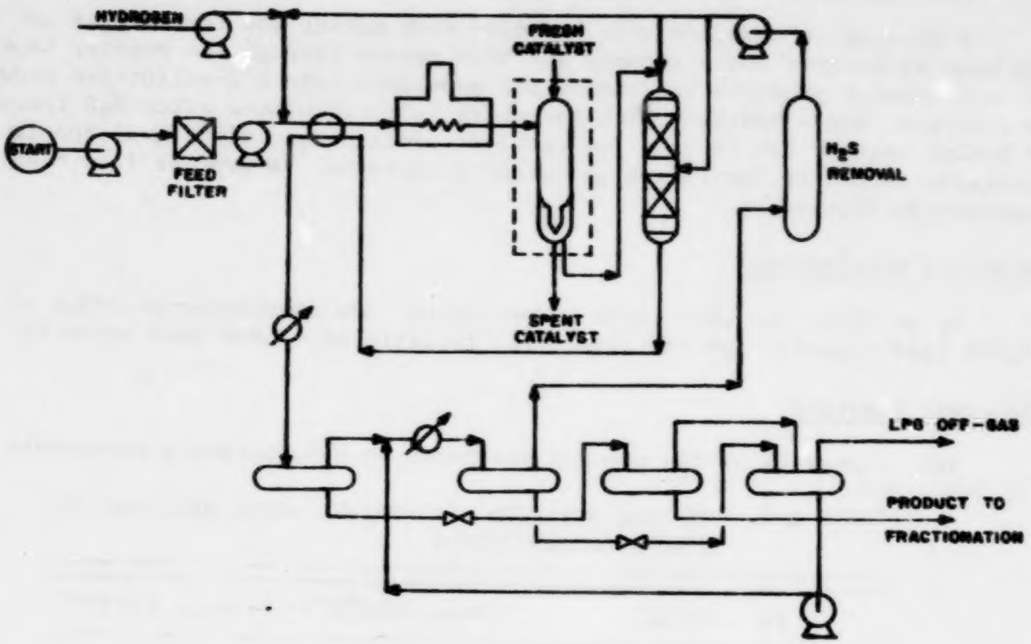
HYDROGEN
FRESH CATALYST
START
FEED FILTER
$H_2S$ REMOVAL
SPENT CATALYST
LPG OFF-GAS
PRODUCT TO FRACTIONATION

Figure A-4. Shell residual oil hydrodesulfurization.

The estimated cost of utility requirements for this Shell hydrodesulfurization process are given in Table A-5. The catalyst cost has been forecasted through use of a Nelson Refinery Operating Index of 295 for the year 1980.

TABLE A-5. ESTIMATED OPERATING COST OF THE SHELL RESIDUAL OIL HYDRODESULFURIZATION PROCESS, 1980

| Utilities | Requirement, per bbl feed | Unit cost | Cost, ¢ per bbl feed |
|---|---|---|---|
| Hydrogen | 1020 scf | \$1.00/Mscf | 102 |
| Electricity | 6 kWh | \$0.03/kWh | 18 |
| Fuel | 65.5 MBtu | \$3.25/MMBtu | 21.3 |
| Steam, med. pres. | 15 lbs | \$3.25/Mlbs | 4.9 |
| Cooling water | 225 gal | \$0.05/1000 gal | 1.1 |
| Catalyst | | | 21.0 |

## HYDROFINING (EXXON)[8]

This system improves the quality of a wide variety of petroleum feedstocks by catalytic treatment with hydrogen. The process can be used to remove sulfur and nitrogen as well as improve the odor, color, stability, and burning characteristics of feeds ranging from light ends to heavy distillate gas oil and lube stocks.

### Process Description

The petroleum feedstock is heated to a temperature between 400 and 700°F, and then passed to a fixed bed reactor along with hydrogen rich gas. The feedstock is treated at pressures between 200 to 500 psig in the presence of a regenerable metal oxide catalyst. The reactor effluent is cooled and the hydrogen rich gas is separated for use in other operations. After separation, the product is stripped for removal of residual hydrogen sulfide. The process flow diagram is shown in Figure A-5.

### Stage of Development

Approximately 225 units are in operation or are being designed with a total capacity of 4,000,000 bpsd.

### Economic Forecast

The economics of the Exxon Hydrofining Process are given in Table A-6.

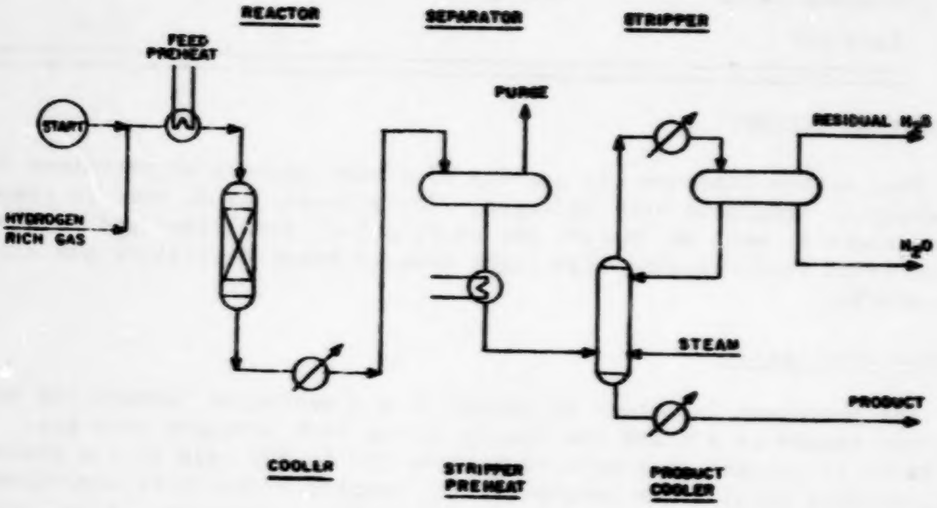
REACTOR
SEPARATOR
STRIPPER
FEED PREHEAT
PURGE
START
RESIDUAL $H_2S$
HYDROGEN RICH GAS
$H_2O$
STEAM
PRODUCT
COOLER
STRIPPER PREHEAT
PRODUCT COOLER

Figure A-5. Exxon Hydrofining Process.

## TABLE A-6. ESTIMATED COST OF EXXON HYDROFINING, 1980

| Investment* | | | Cost, $ per bpsd |
|---|---|---|---|
| Basis: Direct material and labor | | | 102 - 384 |
| Utilities | Requirements | Unit Cost | Cost, ¢ per bbl feed |
| Electricity | 0.3 to 1.0 kWh/bbl | $0.03/kWh | 0.9 to 3 |
| Steam, low pressure | 5 to 12 lb/bbl | $2.00/Mlbs | 1 to 2.4 |
| Fuel | 0 to 30 MBtu/bbl | $3.25/MMBtu | 0 to 9.8 |
| Cooling water | 0 to 70 gal/bbl | $0.05/Mgal | 0 to 0.4 |
| Catalyst replacement | | | 0.3 |
| Hydrogen | | | 60.0 |
| Annualized capital | | | 4.6 to 17.6 |
| Maintenance | | | 0.9 to 3.5 |
| Property tax and insurance | | | 0.6 to 2.4 |
| Operating labor and supervision | | | 3.0 to 4.0 |
| Administration, misc. supply, and overhead | | | 0.9 to 3.5 |
| Total operating cost, ¢/bbl | | | 78.4 to 105.9 |

*Wide range of investment cost due to variety of applications; large virgin feed units tend to be in the lower cost range while small cracked stock feed units are covered by the higher cost range.

### HYDROFINING (BP)[9]

The system is used to remove sulfur from a wide range of distillate feedstocks by catalytic hydrogenation. Feedstock can range from light gasolines to vacuum gas oils up to 1020°F end point, including catalytic cracker cycle oil or coke gas oil components.

### Process Description

Feedstock is mixed with hydrogen rich gas, heated, and passed through a fixed bed desulfurization catalyst reactor. The hot reactor effluent is cooled and separated into liquid and gaseous streams at high pressure. The separated gas stream is recycled to minimize makeup hydrogen requirements. The liquid product stream passes to a low pressure separator for dissolved gas removal prior to entering a stripper column where hydrogen sulfide and light ends are removed. The advantages of the process include:

- Easily regenerable catalyst
- Low operating cost
- High yield

A schematic process diagram is shown in Figure A-6.

## Stage of Development

A total of 49 units are in operation or under construction, with a cumulative capacity of 720,000 bpsd.

## Economic Forecast

Economic figures for 1980, considering four different feedstocks, are given in Table A-7. The catalyst cost was updated by using a Nelson Refinery Operating Index of 295.

## ULTRAFINING[10]

The system is used to desulfurize, denitrogenate, and hydrogenate various oils. Typical charges are virgin and cracked stocks including naphthas, kerosene and diesel fractions, and heavy gas oils including vacuum gas oils, decanted oils and lubricating oils.

## Process Description

The process utilizes cobalt-molybdenum or nickel-molybdenum on alumina catalysts for hydrogenation. The catalyst can be regenerated with a cycle life of approximately 1 year. Desulfurization occurs in a single reactor section, followed by fractionation into the desired product streams. A process flow diagram appears in Figure A-7.

## Stage of Development

A total of approximately 550,000 bpsd of capacity is operating or under construction by Standard Oil, and its affiliates and licensees.

## Economic Forecast

Economic data for the Ultrafining Process is given in Table A-8.

## UNICRACKING/HDS[11,12]

The process is used to treat atmospheric and vacuum resids. It is a fixed bed catalytic system which removes sulfur, nitrogen, and metals.

## Process Description[11]

Feedstock and hydrogen rich gas are mixed and heated and sent to a guard chamber for removal of particulate matter and residual salt content. The mixture then enters the main reactors for contact with the catalyst. Reactor

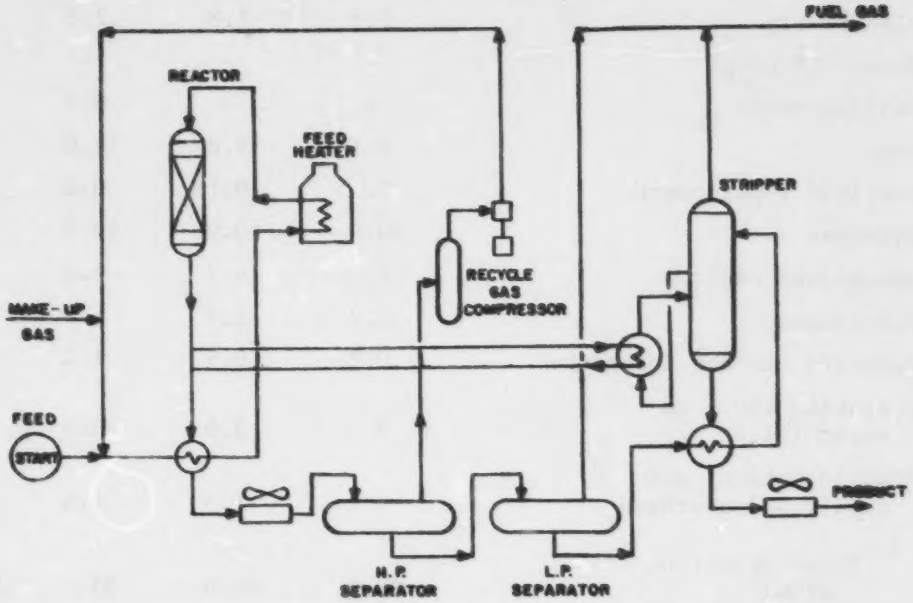
FUEL GAS
REACTOR
FEED HEATER
STRIPPER
RECYCLE GAS COMPRESSOR
MAKE-UP GAS
FEED
START
PRODUCT
H.P. SEPARATOR
L.P. SEPARATOR

Figure A-6. BP Hydrofining Process.

## TABLE A-7. ESTIMATED COST OF BP HYDROFINING, 1980

| | Type of feedstock | | | |
|---|---|---|---|---|
| | Naphtha | Kerosene | Gas oil | Vacuum gas oil |
| Investment, erected cost excluding initial catalyst $ per bpsd | 27 | 146 | 171 | 191 |
| Utilities | | | | |
| Cost, ¢ per bbl | | | | |
| Electricity | 1.6 | 1.8 | 2.8 | 4.2 |
| Steam (25 psig) | - | - | - | 1.6 |
| Cooling water | - | - | 0.2 | 0.1 |
| Fuel | 9.1 | 9.8 | 15.0 | 24.0 |
| Catalyst replacement | 0.15 | 0.15 | 0.2 | 1.0 |
| Hydrogen | 60.0 | 60.0 | 60.0 | 60.0 |
| Annualized capital | 5.8 | 6.7 | 7.8 | 8.7 |
| Maintenance | 1.2 | 1.3 | 1.6 | 1.7 |
| Property tax and insurance | 0.8 | 0.9 | 1.1 | 1.1 |
| Operating labor and supervision | 3.0 | 3.0 | 3.0 | 3.0 |
| Administration, misc. supply and overhead | 1.2 | 1.3 | 1.6 | 1.7 |
| Total operating cost, ¢/bbl | 82.9 | 85.0 | 93.3 | 107.1 |

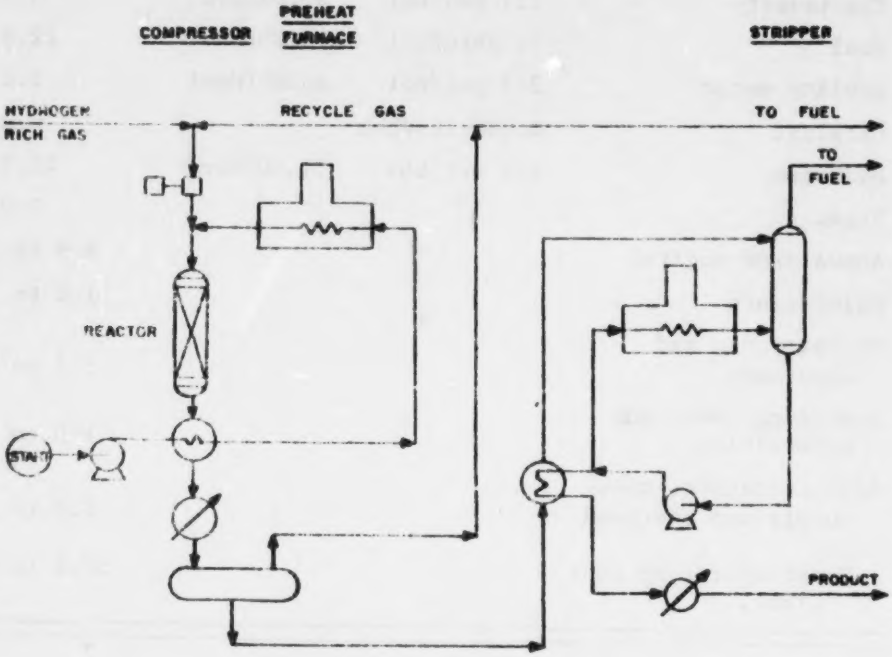
COMPRESSOR
PREHEAT FURNACE
STRIPPER
HYDROGEN RICH GAS
RECYCLE GAS
TO FUEL
TO FUEL
REACTOR
START
PRODUCT

Figure A-7. Ultrafining process.

## TABLE A-8. ESTIMATED COST OF ULTRAFINING, 1980

|  |  |  | Cost, $ per bpsd |
|---|---|---|---|
| **Investment** |  |  |  |
| Basis: 10,000 to 30,000 bpsd distillate ultrafiner |  |  | 192 - 294 |
| Utilities | Requirements | Unit cost | Cost, ¢ bbl feed |
| Electricity | 1.3 kWh/bbl | $0.03/kWh | 3.9 |
| Fuel | 70 MBtu/bbl | $3.25/MMBtu | 22.8 |
| Cooling water | 215 gal/bbl | $0.05/Mgal | 1.1 |
| Catalyst | 0.004 lbs/bbl |  | 0.3 |
| Hydrogen | 125 scf/bbl | $1.00/Mscf | 12.5 |
| Steam |  |  | 2.0 |
| Annualized capital |  |  | 8.8 to 13.4 |
| Maintenance |  |  | 1.8 to 2.7 |
| Property tax and insurance |  |  | 1.2 to 1.8 |
| Operating labor and supervision |  |  | 1.0 to 3.0 |
| Administration, misc. supply and overhead |  |  | 1.8 to 2.7 |
| Total operating cost ¢/bbl |  |  | 57.2 to 66.2 |

product is cooled, separated from recycle gas, and stripped to provide the proper flash point. The recycle gas is treated for $H_2S$ removal and combined with the makeup gas. The schematic process flow diagram is shown in Figure A-8.

## Stage of Development

This process is Union Oil's successor to the Residfining system. One 60,000 bpsd Unicracking HDS facility is in operation.

## Economics

Table A-9 lists the investment and operating costs forecasted to 1980. These figures are updated from a recent article which appeared in Hydrogen Processing.[12] The per barrel utility costs were increased from the original publication to reflect the fact that the authors used a cost of \$2.00/MMBtu for fuel as opposed to our projected unit cost of \$3.25/MMBtu in 1980.

TABLE A-9. ESTIMATED COST OF UNICRACKING/HDS, 1980[12]

| | |
|---|---|
| Cost Basis: 40,000 bpsd North Slope crude charge | |
| Capital Investment, onsite including initial catalyst | \$61.8 × $10^6$ |
| \$ per bpsd | 1545 |
| Direct Operating Costs, ¢/bbl feed | |
| Operating labor and supervision | 4.0 |
| Maintenance | 16.0 |
| Utilities and catalyst | 83.0* |
| Property tax and insurance | 8.0 |
| Annualized capital | 71.0 |
| Administration, misc. supply, and overhead | 16.0 |
| Total operating cost, ¢/bbl | 198.0 |

*Increased from \$0.74 to reflect estimated 1980 fuel cost of \$3.25/MMBtu.

## UNIONFINING[13]

This process is used to accomplish hydrodesulfurization, hydrodenitrogenation, and hydrogenation of a wide variety of petroleum stocks. It is used for upgrading naphthas, kerosene, turbine fuel, and diesel fuel and for desulfurization of vacuum gas oils.

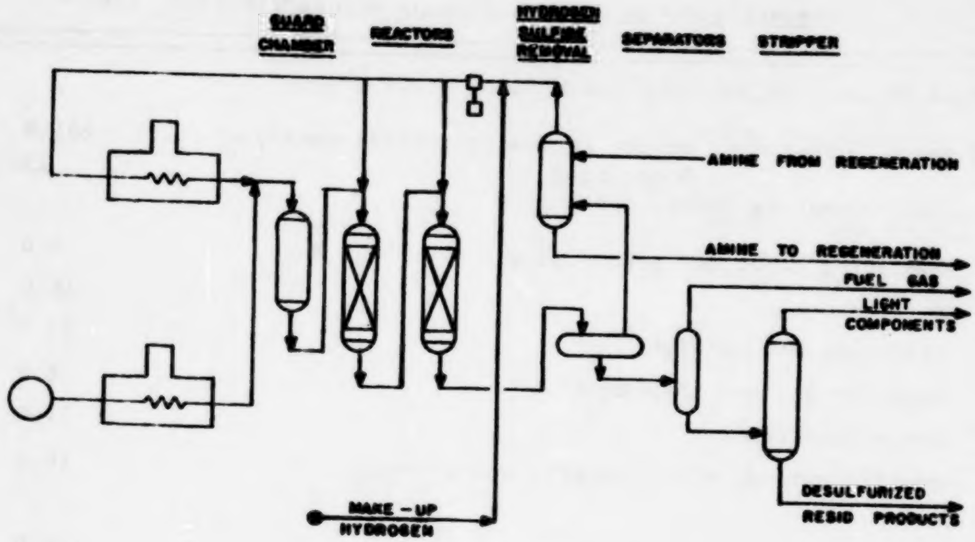
GUARD CHAMBER
REACTORS
HYDROGEN SULFIDE REMOVAL
SEPARATORS
STRIPPER
AMINE FROM REGENERATION
AMINE TO REGENERATION
FUEL GAS
LIGHT COMPONENTS
DESULFURIZED RESID PRODUCTS
MAKE-UP HYDROGEN

Figure A-8. Unicracking/HDS process.

## Process Description

Feedstock and hydrogen rich gas are mixed, heated, and sent to a fixed bed reactor where the mixture is contacted with a high activity catalyst. The catalyst is regenerable with mixtures of air and steam or inert gas. Effluent from the reactor is cooled and passes to a separator where hydrogen rich gas is withdrawn for recycling. Liquid product passes to a stripper for removal of light components and residual hydrogen sulfide, or to a fractionator for splitting into multiple products. A schematic diagram of the process appears in Figure A-9.

## Stage of Development

The process is based on 35 years of hydrotreating experience including more than 75 units in Union Oil and licensee refineries.

## Economic Forecast

The economics of the Unionfining process are given in Table A-10. Catalyst cost is based upon a 1980 Nelson Refinery Operating Index of 295.

TABLE A-10. ESTIMATED COST OF UNIONFINING, 1980

| Investment | | | Cost, $ per bpsd |
|---|---|---|---|
| | | | 224 to 544 |
| Utilities | Requirement | Unit Cost | Cost, ¢ per bbl feed |
| Electricity | 0.5 to 1.5 kWh/bbl | $0.03/kWh | 1.5 to 4.5 |
| Fuel | 40 to 100 MBtu/bbl | $3.25/MMBtu | 13 to 32.5 |
| Catalyst | | | 0.3 to 3.0 |
| Cooling water | | | 1.0 |
| Low pressure steam | | | 2.0 |
| Hydrogen | | | 60.0 |
| Annualized capital | | | 10.2 to 24.8 |
| Maintenance | | | 2.0 to 5.0 |
| Property tax and insurance | | | 1.3 to 3.4 |
| Operating labor, and supervision | | | 2.0 to 4.0 |
| Administration, misc. supply and overhead | | | 2.0 to 5.0 |
| Total operating cost, ¢/bbl | | | 95.3 to 145.2 |

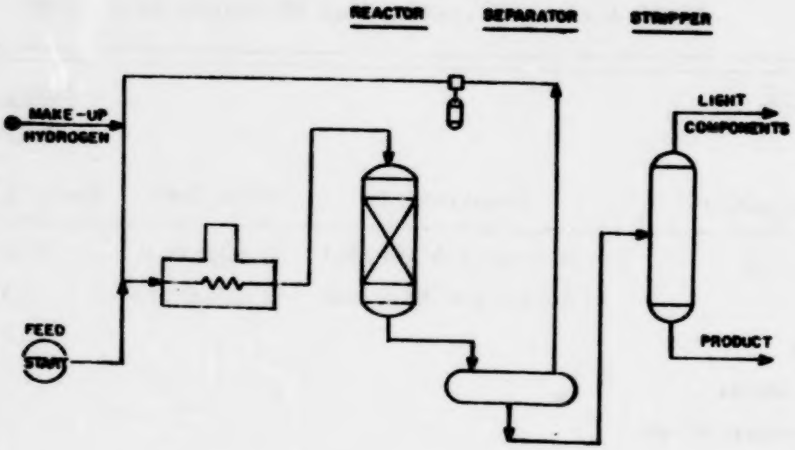
REACTOR
SEPARATOR
STRIPPER
MAKE-UP
HYDROGEN
LIGHT
COMPONENTS
FEED
START
PRODUCT

Figure A-9. Unionfining process.

## SUMMARY

Table A-11 summarizes 1980 capital and operating costs for the HDS processes previously outlined and for systems discussed in the aforementioned environmental assessment.[1] The capital costs presented in Table A-11 have been updated based on information provided in various publications. The basis of individual capital estimates is variable and, in some instances, undefined. In most cases, the published values are battery limit figures. The total annualized costs presented for Flexicoking and LC Fining include allowances for the following additional capital costs; construction management and overhead, engineering and procurement, contingency, fee, new burner cost allowance, startup, and interest during construction. This allows for economic comparison of these two HDS systems with FGD and CAFB systems, as discussed in Appendix B. Therefore, the Flexicoking and LC Fining costs are not on a comparable basis with other HDS systems presented in Table A-11. Finally, some of the operating costs have been estimated by GCA as shown in the footnotes to the table.

## TABLE A-11. SUMMARY OF ESTIMATED 1980 CAPITAL AND OPERATING COSTS ASSOCIATED WITH ALTERNATIVE HYDRODESULFURIZATION PROCESSES

| Process | Licensor | Capacity (bpsd) | Feedstock | Capital[a] cost ($/bpsd) | Operating costs - all values in ¢/bbl of feedstock | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Material costs | | | | |
| | | | | | Estimated[b] total utility costs | Supplemental fuel[c] | Steam | | Cooling[f] water | Process[g] water |
| | | | | | | | Medium[d] | Low[e] | | |
| Autofining | BP | 45,000 | distillate | 95 | | 14.0 | | 2.0[r] | 1.0[r] | |
| Gulfining | Gulf | 35,000 | heavy dist. gas oils | 416 | | 17.9 | 2.0 | | 0.8 | |
| Hydrofining | Exxon | large | virgin feed | 100 | | 5.0[r] | | 1.0 | 0.2[r] | |
| | | small | cracked stock | 385 | | 9.8 | | 2.4 | 0.4 | |
| Hydrofining | BP | 30,000 | naphtha | 127 | | 9.1 | | - | - | |
| | | 30,000 | kerosene | 146 | | 9.8 | | - | - | |
| | | 30,000 | gas oil | 171 | | 15.0 | | - | 0.2 | |
| | | 30,000 | vacuum gas oil | 191 | | 24.0 | | 1.6 | 0.1 | |
| Ultrafining | Standard Oil | 10,000 | distillate | 192 | | 22.8 | | 2.0[r] | 1.1 | |
| | | 30,000 | distillate | 294 | | 22.8 | | 2.0[r] | 1.1 | |
| Unicracking/HDS | Union Oil | 40,000 | North slope crude | 1,565 | 83.0 | | | | | |
| Unionfining | Union Oil | | | 224 | | 13.0 | | 2.0[r] | 1.0[r] | |
| | | | | 554 | | 32.5 | | 2.0[r] | 1.0[r] | |
| Flexicoking | Exxon | 10,700 | vacuum resid 0.3% S prod. | 2,500 | | 20.0 | 75.0 | 14.9 | 0.3 | 6.0 |
| Residue Desulfurization | BP | 50,000 | Kuwait atm. res. 1.0% S prod. | 565 | | 21.5 | 18.5 | | 0.7 | 0.1 |
| | | | 0.5% S prod. | 570 | | 20.2 | 20.5 | | 0.8 | 0.1 |
| Resid Ultrafining | Amoco | 40,000 | West Texas sour | 535 | 32.3 | | | | | |
| LC Fining | CE Lummus Cities Service | 10,700 | Gach Saran atm. resid. 0.5% S prod. | 2,215 | 32.3 | | | | | |
| Resid. Oil Hydrodesulfurization | Shell | | | | | 21.3 | 4.9 | | 1.1 | |
| RCD Unibon | UOP | 50,000 0.3% prod. | Kuwait crude | 1,025 | 26.1 | | | | | |
| Gulf HDS-III | Gulf | 50,000 | 53% Kuwait | 1,100 | | 27.0 | | 23.0 | 0.9 | 0.2 |
| Gulf HDS-IV | Gulf | 50,000 | 53% Kuwait | 1,300 | | 27.9 | | 26.4 | 1.1 | 0.2 |
| IFP Fuel Hydrodesulfurization | IFP | 45,000 | Residual feedstocks | 1,120 | | 81.9 | | 10.1 | 2.4 | 1.1 |
| Shell Gasification | Shell | 59,000 | vacuum residue | 9,600 | | | | | | |
| Demetallization/ Desulfurization | Cities Service | 25,000 | Venezuela medium metals atm. resid. | 1,332 | | 30.0 | | 2.0[r] | 1.0[r] | |
| | | 25,000 | Venezuelan high metals crude, Boscan | 1,264 | | 20.0[r] | | 2.0[r] | 1.0[r] | |
| Residfining | Exxon | 40,000[h] | heavy resids | 1,690 | | 32.5 | | 2.0[r] | 1.5 | |
| Go-fining | Exxon | 40,000[h] | virgin and cracked gas oils | 620 | | 15.3 | | 2.0[r] | 0.3 | |
| Resid Hydroprocessing | Standard Oil | 40,000 | Kuwait atm. resid. | 1,050 | | 28.0 | | 0.5 | 0.8 | 0.6 |

Footnotes to Table:

[a] Capital costs are projected from figures presented by current journal articles or direct correspondence. A Nelson Refinery Capital Cost index (NRC) of 760 was used to represent the year 1980. Past NRC's are published in the Oil and Gas Journal.

[b] Total utility costs which were not available in itemized form from published information; updated by GCA.

[c] Operating cost for supplemental fuel use based on $3.25/MMBtu.

[d] Operating cost for medium pressure steam based on $3.25/M lbs.

[e] Operating cost for low pressure steam based on $2.00/M lbs.

[f] Operating cost for cooling water use based on $0.05/M gal.

[g] Operating cost for process water use based on $1.50/1000 gal.

[h] Operating cost for electricity fuel use based on 3¢/kWh.

[i] Catalyst replacement costs were updated from published data based on a projected Nelson Refinery Operating Cost index of 293 in 1980.

[k] Operating cost for hydrogen requirements is based on $1.00/M scf.

[l] Based on 15 percent of total capital investment per year.

[m] Based on 3 percent of total capital investment per year.

[n] Based on 2 percent of total capital investment per year.

[p] Based on 1.0¢/10,000 bpsd capacity.

[q] Based on 3 percent of total capital investment per year.

[r] Unit operating costs estimated by GCA.

# TABLE A-11 (continued)

| Operating costs - all values in c/bbl of feedstock | | | | | | | | Total operating cost (c/bbl) |
|---|---|---|---|---|---|---|---|---|
| Material costs | | | Annualized costs | | | | | |
| Electricity[h] | Catalyst replacement[j] | Hydrogen[k] | Capital investment[l] | Maintenance[m] | Property tax and insurance[n] | Operating labor and supervision[p] | Administration misc. supply overhead[q] | |
| 3.6 | 0.3 | - | 4.3 | 0.9 | 0.6 | 4.5 | 0.9 | 32.9 |
| 5.1 | 0.3[f] | 35.0 | 19.0 | 3.8 | 2.6 | 3.5 | 3.8 | 93.8 |
| 0.9 | 0.3[f] | 60.0[f] | 4.6 | 0.9 | 0.6 | 4.0[f] | 0.9 | 78.6 |
| 3.0 | 0.3[f] | 60.0[f] | 17.6 | 3.5 | 2.4 | 3.0[f] | 3.5 | 105.9 |
| 1.6 | 0.15 | 60.0[f] | 5.8 | 1.2 | 0.8 | 3.0 | 1.2 | 82.9 |
| 1.8 | 0.15 | 60.0[f] | 6.7 | 1.3 | 0.9 | 3.0 | 1.3 | 85.0 |
| 2.8 | 0.2 | 60.0[f] | 7.8 | 1.6 | 1.1 | 3.0 | 1.6 | 93.3 |
| 4.2 | 1.0 | 60.0[f] | 8.7 | 1.7 | 1.1 | 3.0 | 1.7 | 107.1 |
| 3.9 | 0.3 | 12.5 | 8.8 | 1.8 | 1.2 | 1.0 | 1.8 | 57.2 |
| 3.9 | 0.3 | 12.5 | 13.6 | 2.7 | 1.8 | 3.0 | 2.7 | 66.2 |
| | | | 71.0 | 16.0 | 8.0 | 4.0 | 16.0 | 198.0 |
| 1.5 | 0.3 | 60.0[f] | 10.2 | 2.0 | 1.3 | 2.0[f] | 2.0 | 95.3 |
| 4.5 | 3.0 | 60.0[f] | 24.8 | 5.0 | 3.4 | 4.0[f] | 5.0 | 145.2 |
| 65.0 | 0.3 | | 114.0 | 23.0 | 15.0 | 7.0[f] | 23.0 | 365.0 |
| 10.2 | 16.0 | 60.0[f] | 24.9 | 5.0 | 3.4 | 5.0 | 5.0 | 170.3 |
| 15.6 | 27.0 | 60.0[f] | 26.0 | 5.2 | 3.5 | 5.0 | 5.2 | 189.1 |
| | 12.0 | 60.2 | 24.6 | 4.9 | 3.3 | 4.0 | 4.9 | 146.0 |
| | 49.3 | 140.0 | 101.0 | 20.2 | 13.5 | 7.0[f] | 20.2 | 384.0 |
| 18.0 | 21.0 | 102.0 | | | | | | |
| | 21.6 | 85.0 | 46.8 | 9.4 | 6.3 | 5.0 | 9.4 | 209.6 |
| 23.0 | 26.9 | 66.3 | 50.2 | 10.0 | 6.7 | 5.0 | 10.0 | 249.2 |
| 29.3 | 54.8 | 81.0 | 63.0 | 12.6 | 8.4 | 5.0 | 12.6 | 321.4 |
| 10.7 | 11.0 | | 51.1 | 10.2 | 6.8 | 4.5 | 10.2 | 200.0 |
| | | | 415.00 | 83.0 | 55.6 | 5.9 | 83.0 | > 500.0[f] |
| 10.0[f] | 20.0 | 68.0 | 60.8 | 12.2 | 8.2 | 2.5 | 12.2 | 216.9 |
| 10.0[f] | 17.0 | 103.0 | 57.7 | 11.5 | 7.7 | 2.5 | 11.5 | 263.9 |
| 8.0 | 45.0 | 60.0[f] | 77.2 | 15.4 | 10.3 | 4.0 | 15.4 | 271.3 |
| 6.9 | 4.5 | 60.0[f] | 19.2 | 3.8 | 2.6 | 4.0 | 3.8 | 122.5 |
| 13.2 | 20.0 | 56.0 | 48.0 | 9.6 | 6.4 | 4.0 | 9.6 | 196.7 |

(continued)

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# APPENDIX B

## ECONOMIC COMPARISON OF RESIDUAL OIL UTILIZATION: CAFB, FGD, HDS

### INTRODUCTION

The CAFB is unique as a retrofit application to a natural gas-fired utility. The process can desulfurize and gasify a wide variety of fuels, including high sulfur, high metals, crude oils and high sulfur coals, and produce a low Btu gas suitable for combustion in a conventional gas-fired boiler.

One objective of this study is to update the economic comparison of residual oil desulfurization processes presented in our earlier report.[1] The processes include the emerging technology of chemically active fluid bed (CAFB) gasification, and the existing technologies of flue gas desulfurization (FGD), and hydrodesulfurization (HDS). By comparing CAFB with existing systems, some idea of potential marketability can be determined as compared to conventional systems. Although the conventional systems are capable of providing equivalent desulfurization, they are somewhat limited in matching other inherent capabilities of CAFB, such as demetalization, and reduction of $NO_x$ emissions. Figure B-1 illustrates how the three systems would interface with a conventional utility for combustion of a residual oil feed.

Emissions of $NO_x$ are lower from CAFB, partially due to lower flame temperatures and potentially due to some catalytic fixation of nitrogen in the fuel. The use of HDS and FGD will provide minimal reduction of $NO_x$ emissions because they are associated with conventional combustion temperatures, but will provide $SO_2$ reduction comparable to CAFB. Some HDS systems are capable of demetalizing, but FGD is inferior to both HDS and CAFB in this respect.

A workable total cost comparison of these three systems is difficult to generate due to wide variation in published budget cost estimates. For instance, a recent reference reported unit capital costs for regenerable FGD ranging between \$50 and \$240/kW capacity.[2] Determining representative HDS costs is open to question due to uncertainty in design of the HDS processes. These processes are rarely used to produce only one uniform liquid product so that a larger system might be necessary to produce the same heat input of low sulfur fuel being processed by CAFB. However, the three systems have been compared on the basis of processing 10,700 bpsd of 2.5 to 3.0 percent S residual feed, or the amount required to generate 250 MW of power.

In summary, the utility of the following cost comparison must be assessed on the following basis.

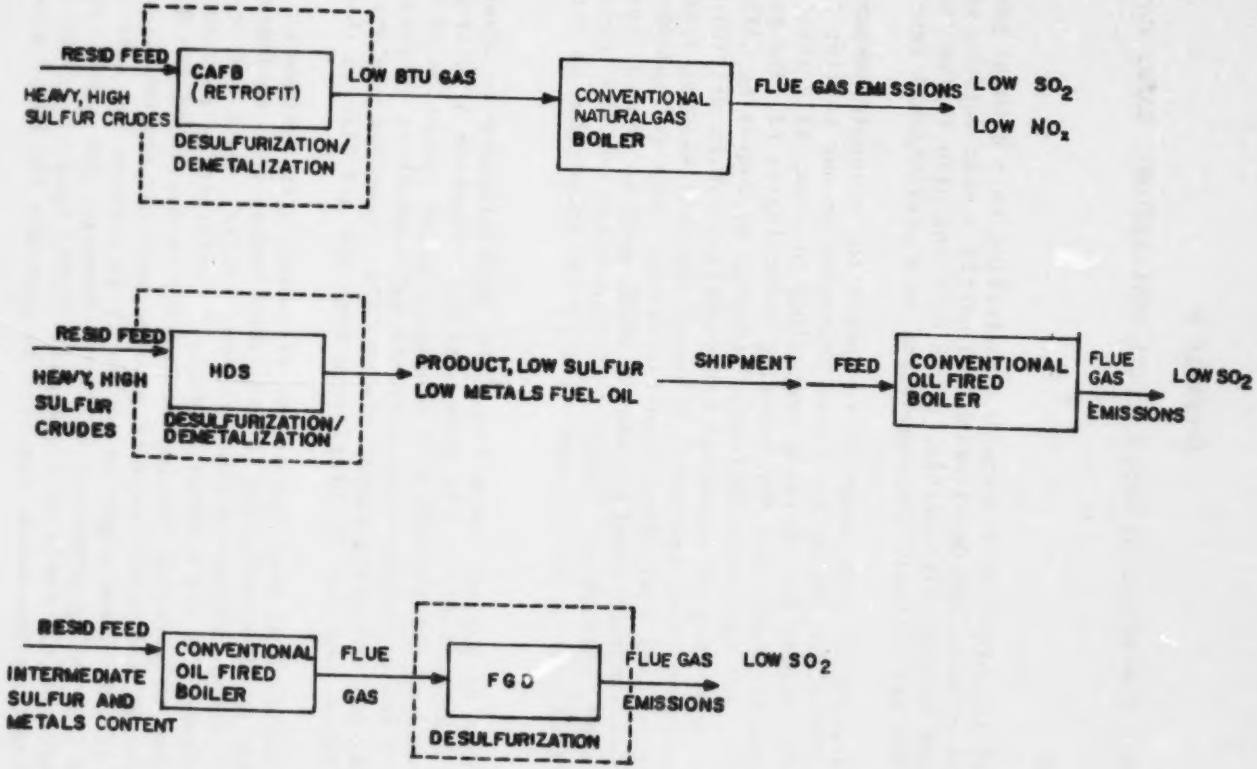
RESID FEED
HEAVY, HIGH SULFUR CRUDES
CAFB (RETROFIT)
DESULFURIZATION/ DEMETALIZATION
LOW BTU GAS
CONVENTIONAL NATURALGAS BOILER
FLUE GAS EMISSIONS
LOW $SO_2$
LOW $NO_x$
RESID FEED
HEAVY, HIGH SULFUR CRUDES
HDS
DESULFURIZATION/ DEMETALIZATION
PRODUCT, LOW SULFUR LOW METALS FUEL OIL
SHIPMENT
FEED
CONVENTIONAL OIL FIRED BOILER
FLUE GAS
EMISSIONS
LOW $SO_2$
RESID FEED
INTERMEDIATE SULFUR AND METALS CONTENT
CONVENTIONAL OIL FIRED BOILER
FLUE GAS
FGD
DESULFURIZATION
FLUE GAS
EMISSIONS
LOW $SO_2$

Figure B-1. Application of CAFB, HDS, and FGD systems at conventional power plants.

Items which are comparable:

- All three systems have equivalent desulfurization capacity.
- All three systems process residual feed at the same rate. (In many HDS applications, it may be desirable to produce other than one end product. Any limitation of production of low sulfur residual oil would necessarily require a larger system to maintain production of 10,700 bpsd of low sulfur fuel. This would increase capital and operating costs.)

Items which are not comparable:

- CAFB generates very low $NO_x$ emissions as compared to equivalent applications of HDS and FGD.
- CAFB and certain HDS systems are equivalent in demetalization capacity; i.e., limitation of trace element air emissions. However, FGD has no demonstrated flue gas demetalizing capacity.
- A wide variety of fuels can be gasified by the CAFB.
- CAFB is a prototype system as opposed to FGD and HDS which are commercially proven.

Another critical factor which complicates an economic comparison based on residual oil utilization is that CAFB and FGD are more aptly suited to coal processing. Considering the current national emphasis on coal utilization as opposed to use of residual and distillate oil, CAFB and FGD are potentially important options for environmentally suitable combustion of coal.

Finally, comparing the three systems exclusively, without considering the cost of the power production train, obscures any cost advantage that gas-firing may have over oil-firing. Gas-firing has negligible requirements for soot blowing and ash handling. In the 250 MW category, this advantage may amount to 5 or 10 percent of the total capital cost.

## BASIS OF COST ESTIMATES

Cost figures were developed for regenerable and nonregenerable (once-through) CAFB and FGD systems. In regenerable systems, sulfur is recovered in elemental or other useful form (such as $H_2SO_4$) and sorbent material is regenerated for reuse, with attendant reduction in solid waste quantities. Regenerable systems require additional processing equipment which add to total capital and operating cost.

The Foster Wheeler Equipment Corporation's design of the CAFB incorporates a RESOX$^{TM}$ processing system which reduces $SO_2$ formed in the regenerator to elemental sulfur. This system is shown in Figure 2 in the main body of the text. It is compared economically with a regenerable magnesium oxide (MgO) FGD scrubbing system. This is currently the only known regenerable FGD system applied at a conventional oil-fired power plant.

A recirculating slurry of MgO or $Mg(OH)_2$ absorbs sulfur dioxide from the flue gas yielding a solution of magnesium sulfite, magnesium sulfate, and unreacted magnesium oxide. The sulfite and sulfate crystals are filtered from the slurry and dried and calcined to regenerate magnesium oxide. Coke is added to reduce the residual magnesium sulfate to MgO and $SO_2$. The recovered $SO_2$ can be processed in an acid plant to yield sulfuric acid or in a Claus unit to produce elemental sulfur. The regenerated MgO is then used as makeup in the FGD system.

The once-through CAFB system is based on use of a dry sulfation technique developed by Westinghouse. In this process, $SO_2$ from the regenerator is contacted with spent stone and boiler cyclone fines to produce a highly sulfated byproduct stone. No byproduct stone regeneration is practiced. A low concentration of $SO_2$ is circulated from the dry sulfation reactor to the gasifier.

The CAFB system with dry sulfation is compared with once-through limestone flue gas desulfurization. A recirculating slurry of limestone is used to scrub $SO_2$ from the flue gas. A waste slurry of calcium sulfate and sulfite is produced and can be dried or disposed of in a liquid state. The costs for limestone FGD include solid waste disposal by discharge to settling ponds.

HDS economics are based on construction and operation of an LC Fining or Flexicoking refining process. These units are licensed by Cities Service and EXXON, respectively. The two processes are representative of demonstrated refinery systems which are capable of desulfurizing and demetalizing petroleum crudes and heavy residual oil. The HDS cost figures presented here are on a once-through nonregenerable basis, although certain HDS processes can operate in a regenerable mode. For instance, a Claus reactor could be added to a Flexicoking installation to convert $H_2S$ to elemental sulfur. Complete operating information on the LC Fining and Flexicoking processes is presented in our initial assessment of the CAFB.[1]

The basis of the cost estimates and final comparison is presented in Table B-1. Some of the background references presented gross costs such as capital costs in terms of \$/bpsd, or operating costs without any indication of quantitative material requirements. Such costs were projected to 1980 by use of the Nelson Refinery Construction Cost Index and the Nelson Refinery Operating Cost Index.[3]

## SUMMARY

The comparative costs for the six systems are presented in Tables B-2 and B-3. The overall format used for presenting capital and operating costs is based on that presented by Westinghouse in their evaluation of fluidized bed combustion.[4]

It is important to note that cost information on these different processes is very limited, and published data tend to vary greatly. The comparison given here may have quantitative inconsistencies based on differing

## TABLE B-1. BASIS OF COST COMPARISON

General

1. All costs represent projections to the year 1980.
2. CAFB and FGD costs are based on battery limits retrofit, and HDS systems are battery limits new.
3. Each system processes liquid fuel at 10,700 bpsd (equivalent to 250 MW capacity).

Capital Costs

1. Direct costs (equipment and labor).
2. Distributable costs (construction management and overhead) at 15 percent of direct costs.
3. Indirect costs (engineering and procurement) at 13.5 percent of direct costs.
4. Contingencies at 7.7 percent of total directs, indirects, and distributables.
5. Fee at 50 percent of contingency.
6. Startup at 8 percent of total investment.
7. Interest during construction at 8 percent of total investment.

Operating Costs

1. Limestone at $25/ton, FOB works.
2. Hydrogen at $1.00/1000 scf.
3. Supplemental fuel at $3.25/MM Btu.
4. Steam, high pressure at $3.25/1000 lbs.
   low pressure at $2.00/1000 lbs.
5. Cooling water at 5¢/1000 gal.
6. Process water at $1.50/1000 gal.
7. Power at 3¢/kWh.
8. Annualized capital at 15 percent/year of total capital investment.
9. Maintenance at 3 percent/year of total capital investment.
10. Property tax and insurance at 2 percent/year of total capital investment.
11. Labor and supervision at 7¢/bbl processed.
12. Administration, miscellaneous supply, and overhead at 3 percent/year of total investment.

(continued)

TABLE B-1 (continued).

CAFB and RESOX™

1. Capital costs based on mid-1975 equipment costs developed by Foster Wheeler.[a]
2. Operating costs are based on:
   - Limestone at 6.3 ton/hour.
   - Anthracite coal to RESOX™ at 2 ton/hour and $50/ton.
   - Electricity at 3¢/kWh, assumed equal to electricity requirements noted for CAFB and dry sulfation, updated from Westinghouse study.[b]

CAFB and Dry Sulfation, Limestone FGD

- Capital and Operating costs interpolated and updated directly from the Westinghouse study.[b]

MgO FGD

- Capital and Operating costs based on latest FGD cost study prepared by McGlamery and Torstrick of TVA.[c]

Flexicoking

- Capital and Operating costs based on published data and additional information provided by EXXON.[d,e,f]

LC Fining

- Capital and Operating costs based on published data and additional information provided by Cities Service.[g,h]

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[a] Chemically Active Fluid Bed Process. Preliminary Process Design Manual. Foster-Wheeler Energy Corp., Livingston, New Jersey. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Contract No. 68-02-2106. 185 p. December 1975.

[b] Keairns, D. L., et al. Fluidized Bed Combustion Process Evaluation (Phase 1-Residual Oil Gasification/Desulfurization Demonstration at Atmospheric Pressure). Volume I - Summary. Prepared for the U.S. Environmental Protection Agency, Office of Research and Development. Publication No. EPA-650/2-75-027a. March 1975. (NTIS No. PB 241-834/AS).

[c] McGlamery, G. G., et al. Flue Gas Desulfurization Economics. Office of Agricultural and Chemical Development, Tennessee Valley Authority. Proceedings: Symposium on Flue Gas Desulfurization, New Orleans, March 1976. Volume I. U.S. Environmental Protection Agency. Publication No. EPA-600/2-76-136a. May 1976.

(continued)

TABLE B-1 (continued).

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[d] Flexicoking Passes Major Test. The Oil and Gas Journal. March 10, 1975. pp. 53-56.

[e] Flexicoking. Hydrocarbon Processing. September 1976.

[f] Correspondence with Mr. Lamont E. Hill, EXXON Research and Engineering Company. October 26, 1977.

[g] Correspondence with Mr. Edward D. Wysocki, Cities Service Research and Development Company. February 27, 1976.

[h] LC Fining. Hydrocarbon Processing. September 1976.

TABLE B-2. ESTIMATED 1980 CAPITAL COSTS FOR REGENERABLE AND NONREGENERABLE CAFB AND FGD SYSTEMS, 250 MW OIL-FIRED POWER PLANTS

| Cost items | Regenerable CAFB and FGD systems | | Nonregenerable CAFB and FGD systems | | Nonregenerable HDS systems | |
|---|---|---|---|---|---|---|
| | CAFB and RESOX$^{TM}$ | MgO FGD | CAFB and Dry sulfation | Limestone FGD | Flexicoking | LC Fining |
| Process equipment in place | 23,044,300 | 6,916,250 | 11,815,600 | 5,162,500 | 7,918,000 | 7,008,500 |
| Process materials and labor | 15,439,700 | 6,916,250 | 15,893,600 | 6,898,600 | 7,918,000 | 7,008,500 |
| Total directs | 38,484,000 | 13,832,500 | 27,709,200 | 12,061,100 | 15,836,000 | 14,017,000 |
| Distributables (15% directs) | 5,772,600 | 2,074,900 | 4,156,400 | 1,829,200 | 2,375,000 | 2,102,600 |
| Subtotal | 44,256,600 | 15,907,400 | 31,865,600 | 13,890,300 | 18,211,000 | 16,119,600 |
| Indirects (13.5% directs) | 5,195,300 | 1,867,300 | 3,740,700 | 1,649,800 | 2,137,900 | 1,892,300 |
| Subtotal base costs | 49,451,900 | 17,774,700 | 35,606,300 | 15,540,100 | 20,348,900 | 18,011,900 |
| Contingency (7.7% base costs) | 3,840,900 | 1,368,600 | 2,741,700 | 1,210,500 | 1,580,300 | 1,386,900 |
| Fee (50% contingency) | 1,920,500 | 684,300 | 1,370,900 | 605,900 | 790,200 | 693,500 |
| Subtotal process investment | 55,213,300 | 19,827,600 | 39,718,900 | 17,356,500 | 22,719,400 | 20,092,300 |
| New ID fan | 342,000 | - | 342,000 | - | - | - |
| Burner costs | 477,000 | - | 477,000 | - | 330,000 | 330,000 |
| Subtotal investment | 56,032,300 | 19,827,600 | 40,537,900 | 17,356,500 | 23,049,400 | 20,422,300 |
| Startup (8% investment) | 4,482,600 | 1,586,200 | 3,243,000 | 1,392,600 | 1,844,000 | 1,633,800 |
| Interest during construction (8% investment) | 4,482,600 | 1,586,200 | 3,243,000 | 1,392,600 | 1,844,000 | 1,633,800 |
| Total | 64,997,500 | 23,000,000 | 47,023,900 | 20,141,700 | 26,737,000 | 23,689,900 |
| $/kW | 260 | 92 | 188 | 81 | 107 | 95 |

TABLE B-3. ESTIMATED 1980 OPERATING COSTS FOR CAFB, FGD AND HDS SYSTEMS, 250 MW OIL-FIRED POWER PLANTS

| Cost items | Regenerable CAFB and FGD systems | | Nonregenerable CAFB and FGD systems | | Nonregenerable HDS systems | |
|---|---|---|---|---|---|---|
| | CAFB and RESOX$^{TM}$ | MgO FGD | CAFB and Dry sulfation | Limestone FGD | Flexicoking | LC Fining |
| Limestone | 1,242,800 | | 1,242,800 | 1,562,500 | - | - |
| Catalyst | - | 3,715,000 | - | - | 11,000 | 1,732,900 |
| Hydrogen | - | | - | - | - | 4,920,900 |
| Supplemental Fuel | 1,180,000[a] | | - | - | 703,000 | 1,135,300 |
| Steam | - | | - | 800,900 | 3,163,500 | |
| Cooling Water | - | | - | | 11,000 | |
| Process Water | - | | | 17,500 | 239,000 | |
| Power | 3,100,000 | | 3,100,000 | 1,181,200 | 1,581,700 | |
| Annualized capital | 9,747,200 | 3,450,000 | 7,053,600 | 3,021,300 | 4,010,600 | 3,553,500 |
| Maintenance | 1,949,400 | 690,000 | 1,410,700 | 604,300 | 802,100 | 710,700 |
| Property tax and insurance | 1,306,100 | 462,300 | 945,900 | 404,900 | 537,400 | 473,800 |
| Labor and supervision | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 |
| Administration, miscellaneous supply, and overhead | 1,949,400 | 690,000 | 1,410,700 | 604,300 | 802,100 | 710,700 |
| Total | 20,724,900 | 9,257,300 | 15,410,800 | 8,446,900 | 12,111,400 | 13,487,800 |
| $/bbl | 5.90 | 2.63 | 4.38 | 2.40 | 3.45 | 3.84 |

[a] Anthracite coal for RESOX$^{TM}$ system.

basic assumptions in the references cited. However, the more important inconsistencies are technical differences with respect to system comparability as pointed out in the introductory section of this Appendix.

This cost summary indicates that regenerable CAFB and FGD systems are more expensive than their once-through counterparts. The CAFB with RESOX™ has the highest capital and operating cost, at $260/kW and $5.90/bbl, respectively. These values are more than double the equivalent MgO FGD control costs. CAFB with dry sulfation is a more cost effective CAFB operation, with operating costs only slightly higher than those associated with the Flexicoking and LC Fining HDS processes. However, capital costs for CAFB, whether regenerable or once-through, are double any other system.

Estimated operating costs are also significantly higher for CAFB, as compared to flue gas desulfurization systems. The CAFB with RESOX™ is $3/bbl more expensive than MgO FGD. CAFB with dry sulfation has an attendant operating cost $2/bbl higher than limestone FGD. In order to operate the CAFB on a competitive basis with flue gas desulfurization systems, high sulfur, high metals crudes must be $2 to $3 per barrel cheaper than low metals, medium sulfur content residual or distillate oils. At present this per barrel differential requirement is roughly twice the market situation.

## COAL UTILIZATION

The total capital cost (design, equipment, and construction) of a 250 MW coal-fired regenerable CAFB is estimated to be approximately 8 to 10 percent greater than an equivalent oil-fired regenerable CAFB system.[5] The additional cost is due to the coal handling system, which adds about 15 percent to the total equipment cost. Similar incremental costs would be applicable for a coal-fired conventional boiler with flue gas desulfurization, so that the overall cost comparison of the two technologies is unchanged. Operating costs for the two systems would also be somewhat higher because of added electricity needs for coal handling. Conventional pulverized coal boilers would have a slightly higher additional operating cost than the coal-fired CAFB system due to greater coal crushing needs.

## REFERENCES

1. Werner, A. S., C. W. Young, M. I. Bornstein, R. M. Bradway, M. T. Mills, and D. F. Durocher. Preliminary Environmental Assessment of the CAFB. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/7-76-017. October 1976. 324 pp. (NTIS No. PB 262-001/AS).

2. Princiotta, F. T. Advances in $SO_2$ Stack Gas Scrubbing. Chemical Engineering Progress. 74(2):58-64. February 1978.

3. Nelson, W. L., Technical Editor and Petroleum Consultant. Nelson Indexes. The Oil and Gas Journal. Published Weekly.

4. Keairns, D. L., et al. Fluidized Bed Combustion Process Evaluation (Phase I - Residual Oil Gasification/Desulfurization Demonstration at Atmospheric Pressure). Volume I - Summary. Prepared for the U.S. Environmental Protection Agency, Office of Research and Development. Publication No. EPA-650/2-75-027a. March 1975. (NTIS No. PB 241-834/AS).

5. Letter correspondence from Mr. Frank D. Zoldak, Foster-Wheeler Energy Corporation, to Mr. Samuel L. Rakes, U.S. Environmental Protection Agency. December 13, 1978.

# APPENDIX C

# RAW DATA FROM FIELD MEASUREMENTS

Sample Control No. RAC#

## ANALYTICAL TRAVELER
Inorganic Gases

(Special Instructions Attached____)

Sample Site CAFB

Type of Source

Test Number RAC#1 Sample Number BAG#1

Sample Description

Responsible Analyst

Date Taken 1/23/78 Date Analyzed 1/23/78

Analyst Signature

### Workup

1. Column flow rate (mℓ/min) 20
2. Recorder speed 2CM/m
3. Full scale (mv)
4. Column pressure (psi)
5. Electrometer set (A/mv)
6. Calibration date
7. Sample size (mℓ) 1
8. Oven temperature ~~(°C)~~ 35°F
9. Attenuation 1024/64
10. Range
11. Observations TCD

### Results

| 12. Param | 13. Sum of peak areas | 14. Concentration (%) | 15. Q. |
|---|---|---|---|
| $O_2$ | | 9.1% | |
| $CO_2$ | | 10.1% | |
| CO | | — | |
| $N_2$ | | | |

Sample Control No.__________

## ANALYTICAL TRAVELER
### Inorganic Gases

(Special Instructions Attached___)

Sample Site CAFB

Type of Source __________

Test Number SASS #1 Sample Number BAG #2

Sample Description __________

Responsible Analyst __________

Date Taken 1/24/78 Date Analyzed 1/25/78

Analyst Signature __________

### Workup

1. Column flow rate (mℓ/min) 30
2. Recorder speed 2 cm/min
3. Full scale (mv) __________
4. Column pressure (psi) 28
5. Electrometer set (A/mv) __________
6. Calibration date __________
7. Sample size (mℓ) 1 ml
8. Oven temperature ~~(°C)~~ 40°F
9. Attenuation 1024 / 64
10. Range __________
11. Observations TCD

### Results

| 12. Param | 13. Sum of peak areas | 14. Concentration (%) | 15. Q. A. |
|---|---|---|---|
| $O_2$ | | 90% | |
| $CO_2$ | | 6.1% | |
| CO | | 0% | |
| $N_2$ | | | |

Sample Control No. BAG#2

## ANALYTICAL TRAVELER

## $C_1 - C_6$

(Special Instructions Attached___)

Sample Site CAFB

Type of Source

Test Number SASS 1

Sample Number BAG#2

Sample Description

Responsible Analyst

Date Taken 1/24/78

Date Analyzed

Analyst Signature

### Workup

1. Column flow rate (mℓ/min) 30
2. Recorder speed 2 cm/min
3. Full scale (mv)
4. Column pressure (psi) 28
5. Electrometer set (A/mv)
6. Calibration date
7. Sample size (mℓ) 1ml
8. Oven temperature (°C) 105°F
9. Flame flow rates (mℓ/min): $H_2$ ___ Air ___
10. Attenuation 8
11. Range
12. Observations FID

### Results

| 13. Param | 14. Sum of peak areas | 15. Concentration ~~(µg/µℓ)~~ ppm/vol | 16. Q. A. |
|---|---|---|---|
| $C_1$ | | 6.5 | |
| $C_2$ | | | |
| $C_3$ | | | |
| $C_4$ | | | |
| $C_5$ | | | |
| $C_6$ | | | |

Page 1 of 1

Sample Control No. RAC #1

## ANALYTICAL TRAVELER

## $C_1 - C_6$

(Special Instructions Attached____)

Sample Site CAFB

Type of Source

Test Number RAC#1 Sample Number BAG #1

Sample Description

Responsible Analyst

Date Taken 1/23/78 Date Analyzed 1/23/78

Analyst Signature

### Workup

1. Column flow rate (mℓ/min) 32 ml/min 2. Recorder speed 2 cm/min
3. Full scale (mv) 4. Column pressure (psi) 30
5. Electrometer set (A/mv) 6. Calibration date
7. Sample size (mℓ) 1 8. Oven temperature (°C) 107°
9. Flame flow rates (mℓ/min): $H_2$ Air
10. Attenuation 16 11. Range
12. Observations FID

### Results

| 13. Param | 14. Sum of peak areas | 15. Concentration ~~(µg/µℓ)~~ ppm | 16. Q. A. |
|---|---|---|---|
| $C_1$ | | 21.4 | |
| $C_2$ | | 2.8 | |
| $C_3$ | | | |
| $C_4$ | | | |
| $C_5$ | | | |
| $C_6$ | | | |

Page 1 of 1

Sample Control No.________

ANALYTICAL TRAVELER

Inorganic Gases

(Special Instructions Attached____)

Sample Site CAFB

Type of Source________

Test Number________ Sample Number Bag #7

Sample Description bag samp'

Responsible Analyst w.P

Date Taken 1/22/78 Date Analyzed________

Analyst Signature________

Workup

1. Column flow rate (mℓ/min) 10
2. Recorder speed 2
3. Full scale (mv)________
4. Column pressure (psi) 9
5. Electrometer set (A/mv)________
6. Calibration date 1/22/78
7. Sample size (mℓ) 1 ml
8. Oven temperature (°C)________
9. Attenuation________
10. Range________
11. Observations________

Results

| 12. Param | 13. Sum of peak areas | 14. Concentration (%) | 15. Q. |
|---|---|---|---|
| $O_2$ | | 5.3 | |
| $CO_2$ | | 6.4 | |
| CO | | 0 | |
| $N_2$ | | 88.1 | |

Sample Control No.__________

# ANALYTICAL TRAVELER

## $C_1 - C_6$

(Special Instructions Attached___)

Sample Site CAFB

Type of Source __________

Test Number __________ Sample Number Bag samp 3

Sample Description Integrated bag samp

Responsible Analyst LP

Date Taken 1/27/78 Date Analyzed 1/27/78

Analyst Signature __________

## Workup

1. Column flow rate (mℓ/min) 30
2. Recorder speed 2
3. Full scale (mv) __________
4. Column pressure (psi) 22
5. Electrometer set (A/mv) __________
6. Calibration date 1/27/78
7. Sample size (mℓ) 1 ml
8. Oven temperature (°C) 104
9. Flame flow rates (mℓ/min): $H_2$ __________ Air __________
10. Attenuation X 8
11. Range 1
12. Observations __________

## Results

| 13. Param | 14. Sum of peak areas | 15. Concentration (μg/μℓ) | 16. Q. A. |
|---|---|---|---|
| $C_1$ | 0 | 0 | |
| $C_2$ | 0 | 0 | |
| $C_3$ | 0 | 0 | |
| $C_4$ | 0 | 0 | |
| $C_5$ | 0 | 0 | |
| $C_6$ | 0 | 0 | |

Page 1 of 1

%M 8.968

# ANDERSEN IMPACTOR FIELD DATA

PLANT CAPB
LOCATION
BOILER
DATE 1/26/78
ΔH = .77

TIME
RUN NO.
IMPACTOR LOCATION
ORIFICE
NOZZLE DIA.

| STAGE NO. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | F |
|---|---|---|---|---|---|---|---|---|---|
| SUBSTRATE NO. | 48 | 50 | 83 | 54 | 49 | 46 | 52 | 47 | 28 |

leak test = .005

| TRAVERSE POINT | ELAPSED TIME | ORIFICE Δ h "$H_2O$ | ORIFICE t T o °F | ORIFICE S.P. - "Hg |
|---|---|---|---|---|
| | 0 | .77 | 38 38 | .8 |
| | 2 mi | .77 | 38 38 | 1.2 |
| | | | | |
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| | | | | |

Final = 799.708
Initial = 799.056
.642

## ANDERSEN IMPACTOR FIELD DATA

PLANT CAFB
LOCATION
BOILER
DATE 1-27-78

ΔH = .77

TIME 15:00
RUN NO. Impactor Run #3
IMPACTOR LOCATION
ORIFICE
NOZZLE DIA.

| STAGE NO. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | F |
|---|---|---|---|---|---|---|---|---|---|
| SUBSTRATE NO. | 67 | 88 | 73 | 53 | 55 | 51 | 95 | 82 | 30 |

Leak Rate = .002 cfm @ 3" Hg [illegible]

| TRAVERSE POINT | ELAPSED TIME | ORIFICE Δh "$H_2O$ | ORIFICE IT °F O | ORIFICE S.P. - "Hg |
|---|---|---|---|---|
| | 0 | .77 | 48 48 | .6 |
| | 2.5 | .77 | 48 48 | .61 |
| | 5 | .77 | 48 48 | .6 |
| | 8 | | | |
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Final = 804.634
Initial = 802.653
1.981

Nozzle was not into the flow until 2.5 min

## ANDERSEN IMPACTOR FIELD DATA

**PLANT** CAFB
**LOCATION**
**BOILER**
**DATE** 6/24/77
Desired ΔH .77

**TIME** 18:00
**RUN NO.** 1
**IMPACTOR LOCATION**
**ORIFICE** DGM 642448
**NOZZLE DIA.** .

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **STAGE NO.** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | F |
| **SUBSTRATE NO.** | 81 | 80 | 75 | 45 | 79 | 74 | 44 | 76 | 32 |

·Leak Rate = .004 @ 5.5"Hg / 60 sec.

1830

| TRAVERSE POINT | ELAPSED TIME | ORIFICE Δh "$H_2O$ | ORIFICE T °F I | O | ORIFICE S.P. - "Hg |
|---|---|---|---|---|---|
| | 0 | .77 | 50 | 49 | .8 |
| | 2.5 | .77 | 49 | 49 | .8 |
| | 5 | .77 | 49 | 49 | .9 |
| | | | | | |
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| | | | | | |

final = 798.916
Initial = 797.163
1.753

Location CAFB
Run # SASS #1
Date 11/29/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | 1.73 | $Vw^{Std}$ | 94.71 |
| Vw (ml) | 2006.4 | $Vm^{Std}$ | 919.167 |
| Vm ($Ft^3$) | 932.936 | $9^r$/DSCF | .9632 |
| Tm ($^oR$) | 525.29 | % M | 9.34 |
| Pb ("Hg) | 29.20 | % Dry Gas | 90.66 |
| Mg. Partic. | 57492.09 | M. W. (Wet) | 28.44 |
| % $CO_2$ | 7.53 | D ($^{Lbs.}/Ft^3$) | .0564 |
| % $O_2$ | 7.8 | % EA | 53.40 |
| % CO | 0 | Vs (fpm) | 400.124 |
| TS ($^oR$) | 1675.16 | Qs ($ft^3$) | 1100.33 |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | 9.08 |
| $\Delta P^{1/2}$ | .10 | % I | 96.59 |
| Cp | .865 | | |
| TT (min) | 280 | | |
| $A_{noz}$ ($ft^2$) | .01227 | | |
| AST ($ft^2$) | 3.976 | | |

# SASS ANALYTICAL DATA

PLANT CIAFD
DATE 1/29/79
SAMPLING LOCATION
SOURCE ~~I.D.~~ 5
RUN NUMBER SASS-1
RECOVERY BY
RECORDED

COMMENTS:

FILTER # 1.3130
TOTAL = .6776 g.

CYCLONES USED:

10μ ✓ 3μ ✓ 1μ ✓
Net. 12.43855 g 28.89202 g Ar 15.48376

VOLUME

| | INITIAL | FINAL |
|---|---|---|
| FIRST IMPINGER | 500 ml | 1,218 ml |
| SECOND IMPINGER | 500 ml | 927 ml |
| THIRD IMPINGER | 500 ml | 490 ml |
| TOTAL | 1500 ml | 2635 ml |

GAIN 1135

CONDENSATE - TRAP GAIN 691

SILICA GEL WEIGHT

| INITIAL | FINAL |
|---|---|
| 1018.00 g | 1198.6 g |
| g | g |
| g | g |
| TOTAL g | TOTAL g |

GAIN 180.6
TOTAL 2006.60

ADDITIONAL COMMENTS:

# SASS FIELD DATA

PLANT CAFB
DATE 1/24
SAMPLING LOCATION
SOURCE I.D.
RUN NUMBER SAA-1
OPERATOR
AMBIENT TEMPERATURE
BAROMETRIC PRESSURE 29.13
STATIC PRESSURE, $(P_S)$
FILTER NUMBER(S)

PROBE LENGTH AND TYPE 6'
NOZZLE I.D. 1.5"
ASSUMED MOISTURE, % 10%
XAD-2 MODULE NUMBER
METER BOX NUMBER OVEN NUMBER
METER $\Delta H_@$
C FACTOR
PROBE HEATER SETTING
OVEN SETTING
REFERENCE ΔP

Reproduced from best available copy.

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY ____ MINUTES

Stop →
Start →
[illegible] →
To 10:23
Thu - 0004
15

| TRAVERSE POINT NUMBER | SAMPLING TIME, MIN | CLOCK TIME (24 HR CLOCK) | GAS METER READING $(V_m)$, FT³ | VELOCITY HEAD $(\Delta P_S)$ IN. $H_2O$ | ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN $H_2O$ DESIRED | ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN $H_2O$ ACTUAL | STACK TEMPERATURE $(T_S)$, °F | DRY GAS METER TEMPERATURE INLET $(T_{m_{in}})$ °F | DRY GAS METER TEMPERATURE OUTLET $(T_{m_{out}})$ °F | PUMP VACUUM IN Hg | OVEN TEMPERATURE °F | IMPINGER TEMPERATURE °F | SORBENT TRAP TEMPERATURE °F | PROBE TEMPERATURE °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1825 | 478.075 | – | 1.77 | 1.77 | 203 | 49 | 49 | 0 | 380 | 49 | | 257 |
| | 2 | | 484.440 | | | | | | | | | | | |
| | 2 | | 484.440 | | 1.77 | 1.77 | 207 | ~~51~~ | 49 | 12 | 379 | 75 | ~~42~~ | 261 |
| | 15 | | [illegible] | | 1.77 | 1.77 | 204 | 64 | 53 | 13 | 376 | ~~12~~ void | 47 | 254 |
| | 35 | 1835 | 571.873 | | 1.77 | 1.77 | 204 | 69 | 57 | 13 | 343 | ~~150~~ | 52 | 257 |
| | 45 | | 624.952 | | 1.77 | 1.77 | 206 | 71 | 61 | 14 | 373 | 56 | 67 | 259 |
| | 60 | 19[illegible] | 678.150 | | 1.77 | 1.77 | 209 | 73 | 67 | 14.5 | 388 | 56 | 62 | 259 |
| | 75 | | 731.345 | | 1.77 | 1.77 | 212 | 72 | 65 | 14.5 | 391 | 54 | 63 | 255 |
| | 90 | 1935 | 785.190 | | 1.77 | 1.77 | 213 | 72 | 65 | 14.5 | 393 | 56 | 62 | 263 |
| | 105 | | 837.216 | | 1.77 | 1.77 | 214 | 72 | 65 | 15.0 | 391 | 53 | 63 | 253 |
| | 120 | 2005 | | | | | | | | | | | | |
| | 135 | 2020 | | | 1.77 | 1.77 | 215 | 70 | 64 | 16.0 | 409 | 57 | 66 | 258 |
| | 150 | 2035 | 964.6 | 0.2037 | 1.77 | 1.77 | 216 | 70 | 64 | 17.0 | 410 | 56 | 64 | 257 |
| | 165 | 2050 | 007.535 | | 1.77 | 1.77 | 217 | 71 | 64 | 17.5 | 409 | 54 | 65 | 260 |
| | 180 | 2105 | 0635 | | 1.77 | 1.77 | 220 | 73 | 65 | 18.3 | 409 | 55 | 68 | 258 |
| | 195 | 2120 | 116.2[illegible] | | 1.77 | 1.77 | 221 | 73 | 66 | 18.8 | 409 | 56 | 64 | 261 |
| | 210 | 2135 | 175.035 | | 1.77 | 1.77 | 223 | 72 | 65 | 19.0 | 408 | 49 | 64 | 263 |
| | 225 | 2150 | 231.8[illegible] | | 1.77 | 1.77 | 224 | 73 | 66 | 20.5 | 410 | 48 | 63 | 255 |
| | 240 | 2205 | 285.810 | | 1.77 | 1.65 | 225 | 72 | 65 | 20.5 | 410 | 47 | 63 | 260 |
| | 255 | 2220 | 334.0[illegible] | | 1.77 | 1.60 | 227 | 71 | 65 | 20.5 | 411 | 47 | 64 | 260 |
| TOTAL | | ● | 860.935 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| AVERAGE | ● | ● | ● | ● | ● | | | 65.250 | | ● | ● | ● | ● | ● |

Imp & og/med was circulating pump [illegible]

COMMENTS XAD
[illegible] spot 5.5

4103

## SASS FIELD DATA

PLANT __________
DATE __________
SAMPLING LOCATION __________
SOURCE I.D. __________
RUN NUMBER __________
OPERATOR __________
AMBIENT TEMPERATURE __________
BAROMETRIC PRESSURE __________
STATIC PRESSURE, ($P_S$) __________
FILTER NUMBER(S) __________

PROBE LENGTH AND TYPE __________
NOZZLE I.D. __________
ASSUMED MOISTURE, % __________
XAD-2 MODULE NUMBER __________
METER BOX NUMBER __________ OVEN NUMBER __________
METER ΔH@ __________
C FACTOR __________
PROBE HEATER SETTING __________
OVEN SETTING __________
REFERENCE ΔP __________

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY ____ MINUTES

| TRAVERSE POINT NUMBER | SAMPLING TIME, MIN | CLOCK TIME (24 HR CLOCK) | GAS METER READING ($V_M$), FT³ | VELOCITY HEAD ($\Delta P_S$) IN. H₂O | ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H₂O | | STACK TEMPERATURE ($T_S$), °F | DRY GAS METER TEMPERATURE | | PUMP VACUUM IN Hg | OVEN TEMPERATURE °F | IMPINGER TEMPERATURE °F | SORBENT TRAP TEMPERATURE °F | PROBE TEMPERATURE °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DESIRED | ACTUAL | | INLET ($T_{M_{IN}}$) °F | OUTLET ($T_{M_{OUT}}$) °F | | | | | |
| | 270 | 2231 | 4032.00 | | 1.77 | 1.55 | 338 | 68 | 64 | 20.5 | 447 | 47 | 53 | 298 |
| | 280 | 2240 | 411.011 | | 1.77 | 1.50 | | | | | | | | |
| | | | | | | | 215.116 | 65.28 | | | | | | |
| | | | 932.936 | | | .731 | | | | | | | | |
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| TOTAL | | ● | | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| AVERAGE | ● | ● | ● | ● | ● | | | | | ● | ● | ● | ● | ● |

COMMENTS

Location CAFB

Run # SASS #2

Date 11/20/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | 1.78 | $Vw^{Std}$ | 36.73 |
| Vw (ml) | 778.2 | $Vm^{Std}$ | 266.248 |
| Vm ($Ft^3$) | 268.1168 | $9^r$/DSCF | 1.1994 |
| Tm ($^oR$) | 525.6 | % M | 12.12% |
| Pb ("Hg) | 29.44 | % Dry Gas | 87.88 |
| Mg. Partic. | 20736.2 | M. W. (Wet) | 28.12 |
| % $CO_2$ | 7.53 | D ($^{Lbs.}/Ft^3$) | .0563 |
| % $O_2$ | 7.8 | % EA | 53.6 |
| % CO | 0 | Vs (fpm) | 472.62 |
| TS ($^oR$) | 674.4 | Qs ($ft^3$) | 1271.6 |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | 13.07 |
| $\Delta P^{1/2}$ | .118 | % I | 86.91 |
| Cp | .865 | | |
| TT (min) | 78 | | |
| $A_{noz}$ ($ft^2$) | .01227 | | |
| AST ($ft^2$) | 3.976 | | |

# SASS ANALYTICAL DATA

PLANT CAFB

DATE 1/26/78

SAMPLING LOCATION

~~SOURCE I.D.~~

RUN NUMBER SASS-7

RECOVERY BY

RECORDED

COMMENTS:

FILTER # nck. dat + 1.31023

Total = .365 g

CYCLONES USED:

10μ 4.64813 3μ 9.13672 1μ 6.5854

VOLUME

| | INITIAL | FINAL | |
|---|---|---|---|
| FIRST IMPINGER | 500 ml | 565 ml | |
| SECOND IMPINGER | 500 ml | 574 ml | |
| THIRD IMPINGER | 500 ml | 592 ml | |
| TOTAL | ml | 231 ml | GAIN 231.0 |

CONDENSATE - TRAP GAIN 470.0

SILICA GEL + Con WEIGHT

| INITIAL | FINAL | |
|---|---|---|
| 1019.5 g | 1096.7 g | (750 cg) |
| g | g | |
| g | g | |
| TOTAL g | TOTAL 77.2 g | GAIN 77.2 |

TOTAL 778.2

ADDITIONAL COMMENTS:

## SASS FIELD DATA

PLANT CAFB
DATE 1-26-77
SAMPLING LOCATION CAFB/ESSO
SOURCE I.D.
RUN NUMBER 2
OPERATOR
AMBIENT TEMPERATURE 42°F
BAROMETRIC PRESSURE
STATIC PRESSURE, ($P_S$)
FILTER NUMBER(S)

PROBE LENGTH AND TYPE 6'
NOZZLE I.D. 1.5
ASSUMED MOISTURE, % 8
XAD-2 MODULE NUMBER
METER BOX NUMBER  OVEN NUMBER
METER ΔH@
C FACTOR
PROBE HEATER SETTING 350
OVEN SETTING 400
REFERENCE ΔP

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY 15 MINUTES

| TRAVERSE POINT NUMBER | SAMPLING TIME, MIN | CLOCK TIME (24 HR CLOCK) | GAS METER READING ($V_M$), FT³ | VELOCITY HEAD ($\Delta P_S$), IN. H₂O | ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H₂O | | STACK TEMPERATURE ($T_S$), °F | DRY GAS METER TEMPERATURE | | PUMP VACUUM IN Hg | OVEN TEMPERATURE °F | IMPINGER TEMPERATURE °F | SORBENT TRAP TEMPERATURE °F | PROBE TEMPERATURE °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DESIRED | ACTUAL | | INLET ($T_{M_{IN}}$) °F | OUTLET ($T_{M_{OUT}}$) °F | | | | | |
| | 0 | 14:05 | 421.630 | - | 1.78 | 1.78 | 220 | 55 | 55 | 13 | 406 | 48 | 53 | 257 |
| | 15 | 14:20 | 473.698 | | 1.78 | 1.78 | 220 | 70 | 59 | 13.5 | 401 | 54 | 70 | 262 |
| | 30 | 14:35 | 525.550 | | 1.78 | 1.78 | 218 | 74 | 66 | 14.0 | 403 | 60 | 70 | 260 |
| | 45 | 14:50 | 570.245 | | 1.78 | 1.78 | 207 | 76 | 68 | 14.0 | 404 | 59 | 62 | 258 |
| STACK IS DOWN | | 14:50 | 583.472 | 161.842 | | | | | | | | | | |
| STACK UP | | 15:15 | 583.610 | | 1.78 | 1.78 | 207 | 61 | 63 | 15.0 | 407 | 55 | 57 | 257 |
| | 60 | 15:30 | 637.875 | | 1.78 | 1.78 | 220 | 71 | 64 | 16.0 | 401 | 54 | 70 | 253 |
| | 75 | 15:45 | 692.290 | - | 1.78 | 1.78 | 209 | 72 | 65 | 16.0 | 400 | 52 | 63 | 261 |
| STACK DOWN | | 15:48 | 701.888 | 118.278 | | | | | | | | | | |
| | | | | | | | | | | | | | | |
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| | | | 280.120 | | | | | | | | | | | |
| | — Leak Rate | | 12.09 | | | | | 68.429 | 62857 | | | | | |
| TOTAL | 78 | ● | 268.168 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| AVERAGE | ● | ● | ● | ● | ● | 1.78 | 214.429 | 65.643 | | ● | ● | ● | ● | ● |

COMMENTS Leak Rate = .155 cfm @ 20" Hg/60 sec.

45
8

583.47
421.63
161.84

701.88
583.61
118.27

280.1

Location CAFB
Run # 1 (RAC.)
Date 1|2[illegible]|78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | .88 | $Vw^{Std}$ | 2.26 |
| Vw (ml) | 47.95 | $Vm^{Std}$ | 29.53 |
| Vm ($Ft^3$) | 30.678 | $g^r$/DSCF | 1.038 |
| Tm ($^oR$) | 536.6 | % M | 7.12 |
| Pb ("Hg) | 29.20 | % Dry Gas | 92.88 |
| Mg. Partic. | 1990.35 | M. W. (Wet) | 29.016 |
| % $CO_2$ | 9.1 | D ($^{Lbs.}/Ft^3$) | .0667 |
| % $O_2$ | 10.1 | % EA | 89.93 |
| % CO | 0 | Vs (fpm) | 368.2[illegible] |
| TS ($^oR$) | 583.3 | Qs ($ft^3$) | 120[illegible].[illegible] |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | ~~[illegible]~~ 10.68 |
| $\Delta P^{1/2}$ | .1 | % I | 119.7 |
| Cp | .865 | | |
| TT (min) | 60 | | |
| $A_{noz}$ ($ft^2$) | .001364 | | |
| AST ($ft^2$) | 3.976 | | |

## PARTICULATE CLEAN UP AND REPORT SHEET

**Run Date:** 1/23/77
**Client:** CAFB
**Run No.:** RAC #1
**W. O. No.:**
**Sample Box No.**
**Plant:** ESSO
**Operator:**
**Sampling Location:**

**FRONT HALF** — **Laboratory Results**

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. ______ Residue ______ mg

Cyclone and Flask-Acetone wash Lab No. ______ Residue ______ mg

| Filter No. | Lab No. | Weight Results |
|---|---|---|
| G-61 | | 1.03036 g. |
| Cyclone | | 0.81014 g |
| | | .14985 mg |
| | TOT. | 1.99035 g |

+cyclone

Filter particulate weight 18405 mg

FRONT HALF Sub Total ______ mg

**BACK HALF**

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder

[illegible] as method 8 see sheet

Lab No. ______

Collected on 0.22μ Filter ______ mg

Aqueous Residue ______ mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash

Lab No. ______ Residue ______ mg

BACK HALF Sub Total ______ mg

TOTAL WEIGHT ______ mg

**MOISTURE**

| Impingers | wt before | wt after |
|---|---|---|
| 1 | 583.01 | 576.11 |
| 2 | 587.48 | 622.01 |
| 3 | 587.52 | 599.15 |
| | | 1797.27 |

Final Volume 1797.27
Initial Volume 1758.01
Net Volume 39.26

**Silica Gel**

| | | | | |
|---|---|---|---|---|
| Weight after test: | 254.09 | | | |
| Weight before test: | 245.4 | | | |
| Net Weight | 8.69 | | | |
| Container No.: | 1. | 2. | 3. | 4. |

TOTAL WEIGHT-Silica Gel 8.69 gm

TOTAL VOLUME-Impingers 39.26 ml

TOTAL MOISTURE 47.95 gm

Comments:

LAB: DATE RECEIVED ______
DATE REPORTED ______

ANALYTICAL CHEMIST

HPS/5/77

**PLANT** CAEB

**DATE** 23-1-78

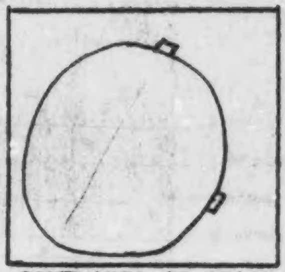
**RUN NO.** 1

**STACK DIAMETER, in.** 29.75

**BAROMETRIC PRESSURE, in.Hg.** 29.20

**STATIC PRESSURE IN STACK($P_g$), in. Hg.**

**OPERATORS**



SCHEMATIC OF STACK CROSS SECTION

| Traverse point number | Velocity head, in. $H_2O$ | $\sqrt{\Delta_p}$ | Stack Temperature($T_S$), °F |
|---|---|---|---|
| 1 | .007 | .084 | 114 |
| 2 | .007 | .084 | 114 |
| 3 | .01 | .10 | 114 |
| 4 | .007 | .084 | 114 |
| 5 | .007 | .084 | 114 |
| 6 | .01 | .10 | 115 |
| 7 | .01 | .10 | 116 |
| 8 | .01 | .10 | 113 |
| 9 | .01 | .10 | 105 |
| 10 | .01 | .10 | 96 |
| 11 | .012 | .11 | 91 |
| 12 | .017 | .13 | 64 |
|  |  |  |  |
| AVERAGE: |  | .098 | 106 |

$$V_s = 5130 (C_p)(\sqrt{\Delta B})(\sqrt{T_S}) \left[\frac{1}{P_s \times M_w}\right]^{\frac{1}{2}}$$

$$V_s = (5130)(.865)(.098)(23.8) \left[\frac{1}{29.20 \times 290}\right]^{\frac{1}{2}}$$

$V_s$ = 355.7 AFPM

Sheet 1 o. 2

# PARTICULATE FIELD DATA

Client CLCB

**VERY IMPORTANT - FILL IN ALL BLANKS**

W. O. No.

Read and record at the start of each test point

Plant

Run No. 1

Location

Date 1-24-77

Operator

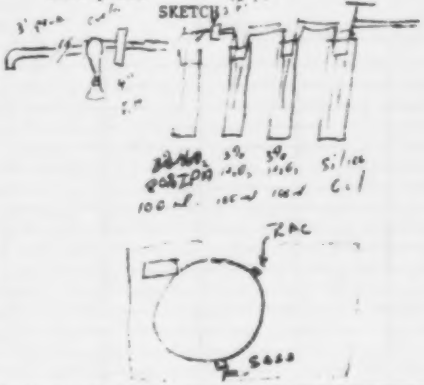
Sample Box No.

Meter Box No. 2257

Meter∆H

C Factor

SKETCH



Pitot Number & Side

Pilot tube CP

Filter No.

Ambient Temp. °F

Bar. Press. "Hg 29.20

Assumed Moisture % 10

Heater Box Setting, °F

Nozzle #/Dia., In. 1/2

Probe Length 3

Probe Heater Setting 300°

Avg.∆P  Avg. ∆H

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. H2O ∆P | ORIFICE ∆ H IN. $H_2O$ DESIRED | ORIFICE ∆ H IN. $H_2O$ ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP. °F | IMPINGER TEMP. °F | STACK PRESS IN. Hg. | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1840 | 0 | 112.067 | .01 | .60 | .60 | 76 | 66 | 3 | 231 | 36 | | 108 |
| 2 | | | 5 | 114.665 | .01 | .65 | .65 | 76 | 68 | 4 | 226 | 36 | | 113 |
| 3 | | | 10 | 116.665 | .01 | .65 | .85 | 80 | 68 | 4 | 238 | 35 | | 121 |
| 4 | | | 20 | | .01 | .9 | .9 | 82 | 68 | 4 | 237 | 34 | | 128 |
| 5 | | | 20 | | .01 | .95 | .95 | 86 | 66 | 4 | 262 | 34 | | 123 |
| 6 | | | 25 | | .01 | .93 | .93 | 86 | 68 | 4.5 | 277 | 34 | | 123 |
| 7 | | | 30 | 127.185 | .01 | .95 | .95 | 86 | 68 | | 225 | 34 | | 115 |
| 8 | | | 35 | 129.818 | .01 | .93 | .93 | 86 | 68 | 4.5 | | | | 110 |
| 9 | | | 40 | | .01 | .95 | .95 | 88 | 70 | 5 | 206 | 35 | | 82 |
| 10 | | | 45 | | .01 | .87 | .87 | 90 | 70 | 5 | 216 | 36 | | 162 |
| 11 | | | 50 | 137.950 | .01 | .92 | .92 | 90 | 70 | 5.5 | 176 | 56 | | 151 |
| | | | | TOTAL | | | | | | | | | | |

**Meter leak check:**

Before test: ____ CF ____ Sec ____ in.Hg

After test: ____ CF ____ Sec ____ in.Hg

Static Pressure (PST) Port ____ in.$H_2O$ ____

COMMENTS:

| before | after | wt $H_2O$ |
|---|---|---|
| impinger 3: 587.52 | | |
| impinger 2 587.48 | | |
| impinger 1 583.01 | | |
| impinger 4 | | |

Leak Rate = .005

C-21

Client CAFB

**PARTICULATE FIELD DATA**
(continued)

Sheet 2 of 2

W.O. No. ________

Plant [illegible]

Location ________

Run No. 1

Date 1-23-77

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. $H_2O$ $\Delta P$ | ORIFICE $\Delta H$ IN. $H_2O$ DESIRED | ORIFICE $\Delta H$ IN. $H_2O$ ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP °F | IMPINGER TEMP °F | STACK PRESS IN. Hg | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 12 |  | 55 | 140.- | .21 | .92 | .92 | 90 | 70 | 5.5 | 200 | 35 |  | 140 |
|  |  |  | 60 | 143.046 |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | Avg. | 30.978 | .21 | 0.89 | 0.89 | 84.67 | 68.6 |  | 235 | 35 |  | 123.333 |
|  |  | Leakage | – | .3 |  |  |  | 76.6 |  |  |  |  |  |  |
|  |  | Total | = | 30.678 |  |  |  |  |  |  |  |  |  |  |
|  |  |  | TOTAL |  |  |  |  |  |  |  |  |  |  |  |

**Meter leak check during test:**

| | | | Meter stop | Reading start |
|---|---|---|---|---|
| ___ CF | ___ Sec | ___ in.Hg's | ___ | ___ |
| ___ CF | ___ Sec | ___ in.Hg's | ___ | ___ |

Static Pressure: Port ___ ___ ___
in.$H_2O$ ___ ___ ___

COMMENTS:

## GASEOUS SAMPLING
## IMPINGER TRAIN

Client: CAFB

Personnel:

Location:

Sample location: ESSO

W.O. No.

Date: 1/23/77

Barometric Pressure:

| | | | | | | |
|---|---|---|---|---|---|---|
| Pollutant and Run No. | | SO2/SO3 | | | | |
| Time | F. | 60 MIN | | | | |
| | S. | • | | | | |
| | T. | 60 MIN | | | | |
| Gas Meter | F. | 143.045 | | | | |
| | S. | 112.067 | | | | |
| Total ft.$^3$ | | 30.978 | | | | |
| Vacuum In. Hg. | F. | 5.5 | | | | |
| | S. | 3.0 | | | | |
| | Av. | 4.25 | | | | |
| Inlet Dry Gas Meter Temp. °F. | F. | 90 | | | | |
| | S. | 76 | | | | |
| | Av. | 83 | | | | |
| Outlet Dry Gas Meter Temp. °F | F. | 70 | | | | |
| | S. | 66 | | | | |
| | Av. | 68 | | | | |
| Impinger Volumes Sol'n A | F. | | | | | |
| | S. | | | | | |
| | Net. | | | | | |
| Impinger Volumes Sol'n B | F. | | | | | |
| | S. | | | | | |
| | Net. | | | | | |
| Silca Gel gms | F | 254.09 | | | | |
| | S | 245.4 | | | | |
| | N | 8.69 | | | | |
| Filter or Thimble # | | | | | | |

NOTES: run set up as combination method 5/method 8.

Location CAFB
Run # RAC #2
Date 1/25/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | 1.20 | $Vw^{Std}$ | 2.315 |
| Vw (ml) | 49.050 | $Vm^{Std}$ | 32.740 |
| Vm ($Ft^3$) | 33.804 | $g^r$/DSCF | 1.529 |
| Tm ($^oR$) | 539.83 | % M | 6.604 |
| Pb ("Hg) | 29.54 | % Dry Gas | 93.40 |
| Mg. Partic. | 3250.97 | M. W. (Wet) | 28.59 |
| % $CO_2$ | 6.1 | D ($^{Lbs.}/Ft^3$) | .058 |
| % $O_2$ | 9.0 | % EA | 67.096 |
| % CO | 0 | Vs (fpm) | ~~476.196~~ 475.9 |
| TS ($^oR$) | 663.5 | Qs ($ft^3$) | ~~1389.15~~ 1388. |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | 18.20 |
| $\Delta P^{1/2}$ | .121 | % I | ~~113.0~~ ~~112.0~~ 114.3 |
| Cp | .865 | | |
| TT (min) | 60 | | |
| $A_{noz}$ ($ft^2$) | .001364 | | |
| AST ($ft^2$) | 3.976 | | |

Sheet 1 of ______

Client CAFB

W. O. No. ______

Plant CAFE / ESSO

Run No. Ten-X

Location ______

Date 1-25-78

Operator ______

Sample Box No. ______

Meter Box No. 2257

Meter ΔH ______

C Factor ______

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH

Pitot Number & Side ______

Pilot tube CP ______

Filter No. ______

Ambient Temp. °F ~ 54

Bar. Press. "Hg 29.54

Assumed Moisture % 8%

Heater Box Setting, °F ______

Nozzle #/Dia., In. 1/2"

Probe Length 3'

Probe Heater Setting ______

Avg. ΔP ______ Avg. ΔH ______

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. H2O ΔP | ORIFICE Δ H IN. $H_2O$ DESIRED | ORIFICE Δ H IN. $H_2O$ ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP. °F | IMPINGER TEMP. °F | | STACK PRESS IN. Hg. | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | 1730 | 0 | 149.060 | .013 114 | 1.2 | 1.2 | 20 | 65 | 7 | 239 | 53 | | | 216 |
| 9 | | | 5 | | .014 118 | 1.1 | 1.1 | 80 | 66 | 10 | [illegible] | 52 | 19c | | 208 |
| 9 | | | 10 | | .015 122 | 1.2 | 1.2 | 88 | 68 | 10 | 271 | 56 | | | 208 |
| 9 | | | 15 | | .015 122 | 1.2 | 1.2 | 90 | 68 | 11.5 | 280 | 58 | 16c | | 207 |
| 9 | | | 20 | | .015 122 | 1.2 | 1.2 | 72 | 70 | 11.5 | 282 | 60 | | | 206 |
| 9 | | | 25 | | .015 122 | 1.2 | 1.2 | 94 | 70 | 12.0 | 278 | 60 | 18c | | 207 |
| 9 | | | 30 | 165.665 | .015 124 | 1.2 | 1.2 | 94 | 70 | 12.0 | 281 | 60 | 18 | | 207 |
| 9 | | | 35 | | .015 124 | 1.2 | 1.2 | 94 | 71 | 12.0 | 282 | 60 | 17c | | 207 |
| 9 | | | 40 | 171.50 | .015 124 | 1.2 | 1.2 | 94 | 72 | 12.5 | 282 | 60 | | | 194 |
| 9 | | | 45 | 174.402 | .015 122 | 1.2 | 1.2 | 94 | 72 | 12.5 | 279 | 60 | 16c | | 194 |
| 9 | | 1820 | 50 | | .015 124 | 1.2 | 1.2 | 95 | 72 | 13.0 | 288 | 60 | | | 194 |
| | | | | TOTAL | [illegible] | | | | | | | | | | |

203

Meter leak check:

Before test: ______CF______Sec______in.Hg
After test: ______CF______Sec______in.Hg

Static Pressure (PST) Port ______ in.$H_2O$ ______

COMMENTS:

Leak Rate = .037 CFM @ 15" Hg / 60 sec

Set Rec temp @ Point 9 to run test.

Could not Traverse Because Ten-x therm would hit 200°.

Client ____________

## PARTICULATE FIELD DATA
(continued)

Sheet _____ of _____

W.O. No. ____________

Plant ____________ Location ____________

Run No. ____________ Date ____________

| POINT | DISTANCE IN INCHES | CLOCK TIME | | DRY GAS METER, CF | PITOT IN. $H_2O$ $\Delta P$ | ORIFICE $\Delta H$ IN. $H_2O$ | | DRY GAS TEMP. °F | | PUMP VACUUM IN. Hg GAUGE | BOX TEMP °F | IMPINGER TEMP. °F | STACK PRESS IN. Hg | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ACTUAL | RUN | | | DESIRED | ACTUAL | INLET | OUTLET | | | | | |
| 9 | | | 55 | | .015 | 1.3 | 1.3 | 95 | 72 | 14 | 293 | 61 16C | | 194 |
| | | Stop | 60 | 183.284 | | | | | | | | | | |
| | | | | | | | | 90 | 69667 | | | | | 203.5 |
| | | | | 33.804 | .121 | 1.208 | | 72.5 | 33 | | | | | |
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| | | | | | | | | | | | | | | |
| | | | TOTAL | | | | | | | | | | | |

**Meter leak check during test:** Meter stop / Reading start

_____ CF _____ Sec _____ in.Hg's _____ _____

_____ CF _____ Sec _____ in.Hg's _____ _____

Static Pressure: Port _____ _____ _____

in.$H_2O$ _____ _____ _____

COMMENTS:

PLANT CAFB

DATE 1-25-78

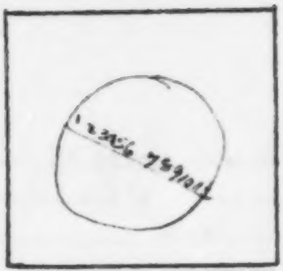
RUN NO. 2

STACK DIAMETER, in.

BAROMETRIC PRESSURE, in.Hg. 29.54

STATIC PRESSURE IN STACK($P_g$), in. Hg.

OPERATORS



SCHEMATIC OF STACK CROSS SECTION

| Traverse point number | Velocity head, in. $H_2O$ | $\sqrt{\Delta_p}$ | Stack Temperature($T_S$), $^oF$ |
|---|---|---|---|
| 1 | .01 | .100 | 191 |
| 2 | .01 | .100 | 192 |
| 3 | .01 | .100 | 194 |
| 4 | .01 | .100 | 196 |
| 5 | .01 | .100 | 197 |
| 6 | .01 | .100 | 197 |
| Static | .08 | | 196 |
| 7 | .013 | .114 | 195 |
| 8 | .015 | .122 | 196 |
| 9 | .015 | .122 | 190 |
| 10 | .015 | .122 | 185 |
| 11 | .017 | .130 | 181 |
| 12 | .020 | .141 | 169 |
| AVERAGE: | | .11[illegible] | 190.2 |

AV. .013

.113

$$V_s = 85.48\ C_p \sqrt{\Delta p}_{avg} \sqrt{\frac{T_{s\,avg} + 460}{P_s M_s}}$$

$$V_s = 85.48\ (.865) \sqrt{(.113)} \sqrt{\frac{190 + 460}{(29.54)\ 29.3}}$$

$V_s$ = 7.24 ft/sec

## PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/25/78
Client:
Run No.: RAC-2
W. O. No.:
Sample Box No.
Plant:
Operator:
Sampling Location: CAFB

**FRONT HALF**

**Laboratory Results**

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. ______ Residue ______ mg

Cyclone and Flask-Acetone Wash Lab No. ______ Residue ______ mg

| Filter No. | Lab No. | Weight Results |
|---|---|---|
| 6-82 | | 2.18645 mg |
| Cyclon | | 0.69625 mg |
| RINSE | | .36827 mg |
| | | 3.25097 mg |

Filter particulate weight 2882.7 mg

FRONT HALF Sub Total ______ mg

**BACK HALF**

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder

Lab No. ______

Collected on 0.22µ Filter ______ mg

Aqueous Residue ______ mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash

Lab No. ______ Residue ______ mg

BACK HALF Sub Total ______ mg

TOTAL WEIGHT ______ mg

**MOISTURE**

**Impingers**

| | | gm |
|---|---|---|
| 100 - | 138 | 38 |
| 100 - | 100 | 0 |
| | 0 | 0 |

Final Volume
Initial Volume
Net Volume 38 ml

**Silica Gel**

| | | | | |
|---|---|---|---|---|
| Weight after test: | 263.25 | | | |
| Weight before test: | 252.2 | | | |
| Net Weight | 11.050 | | | |
| Container No.: | 1. | 2. | 3. | 4. |

TOTAL WEIGHT-Silica Gel 11.050 gm

TOTAL VOLUME-Impingers 38.0 ml

TOTAL MOISTURE 49.050 gm

Comments:

LAB: DATE RECEIVED
DATE REPORTED

ANALYTICAL CHEMIST

HFS/5/77

Location CAFB
Run # RAC #3
Date 2/26/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | 1.12 | $Vw^{Std}$ | 3.23 |
| Vw (ml) | 68.48 | $Vm^{Std}$ | 32.876 |
| Vm ($Ft^3$) | 33.77 | $g^r$/DSCF | .990 |
| Tm ($^oR$) | 535.154 | % M | 8.95 |
| Pb ("Hg) | 29.44 | % Dry Gas | 91.05 |
| Mg. Partic. | 2114.68 | M. W. (Wet) | 28.436 |
| % $CO_2$ | 7.53 | D ($^{Lbs.}/Ft^3$) | .059 |
| % $O_2$ | 7.8 | % EA | 53.60 |
| % CO | 0 | Vs (fpm) | 464.23 |
| TS ($^oR$) | 648.08 | Qs ($ft^3$) | 1346.7<br>[illegible] |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | 11.48 |
| $\Delta P^{1/2}$ | .119 | % I | 3<br>118.00 |
| Cp | .865 | | |
| TT (min) | 60 | | |
| $A_{noz}$ ($ft^2$) | .001364 | | |
| AST ($ft^2$) | 3.976 | | |

Sheet 1 of 2

Client CAFB

W. O. No.

Plant

Run No. ~~SASS#2~~ RAC#3

Location CAFB

Date 11/26/78

Operator

Sample Box No.

Meter Box No.

Meter∆H

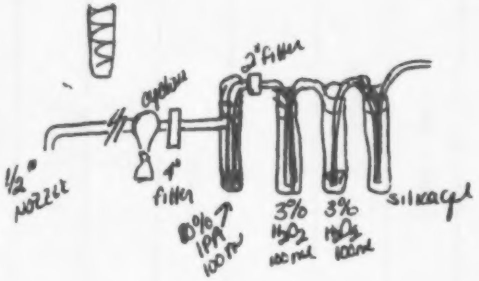
C Factor

# PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH



Pitot Number & Side

Pilot tube CP

Filter No. 616A

Ambient Temp. °F

Bar. Press. "Hg 29.44

Assumed Moisture %

Heater Box Setting, °F

Nozzle #/Dia., In. 1/2"

Probe Length 3'

Probe Heater Setting

Avg.∆P  Avg. ∆H

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. H2O ∆P | ORIFICE ∆ H IN. H2O DESIRED | ORIFICE ∆ H IN. H2O ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP. °F | IMPINGER TEMP. °F | STACK PRESS IN. Hg. | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 |  | 1404 | 0 | 183.532 | .016 | .66 | .66 | 55 | 55 |  | [illegible] | 46 |  | 207 |
| 2 |  | 5 | 5 | 18[illegible] | .012 .100 | .80 | .80 | 63 | 66 | 5 | 265 | 45 |  | 213 |
| 3 |  | 10 | 10 | 188.86 | .014 .12 | .93 | .93 | 74 | 58 | 5 | 261 | 46 |  | 217 |
| 4 |  | 15 | 15 | 190.95 | .009 .095 | .41 | .41 | 81 | 60 | 4 | 255 | 48 |  | 219 |
| 5 |  | 20 | 20 | 192.97 | .013 .11 | .86 | .86 | 83 | 63 | 5 | 251 | 43 |  | 221 |
| 6 |  | 25 | 25 | 194.90 | .017 .15 | 1.6 | 1.6 | 86 | 66 | 6 | 235 | 49 |  | 221 |
| 7 |  | 30 | 30 | 198.70 | .017 .130 | 1.4 | 1.4 | 89 | 68 | 6 | 276 | 50 |  | 219 |
| 8 |  | 40 | 35 | 201.[illegible] | .014 .118 | 1.0 | 1.0 | 91 | 70 | 5 | 310 | 53 |  | 212 |
| 9 |  | 45 | 40 | 204.6 | .018 .15 | 1.5 | 1.5 | 91 | 72 | 7 | 264 | 51 |  | 209 |
| 10 |  |  | 45 | 207.6 | .016 .126 | 1.0 | 1.0 | 94 | 74 | 5 | 270 | 57 |  |  |
| 11 | STOP | 1450 | [illegible] | 208.798 |  |  |  |  |  |  |  |  |  |  |

25.266 TOTAL

Meter leak check:

Before test: ______CF______Sec [illegible] in.Hg

After test: ______CF______Sec______in.Hg

Static Pressure (PST) Port in.H2O

COMMENTS:

IMP #1 584.70

#2 588.38

#3 588.90

Silicagel 136 255.95g.

leak rate = .006 CFM @ 15" Hg [illegible]

1450 - CAFB Unit went Down

Client ______

W.O. No. ______

Plant [illegible]

Run No. [illegible]C-3

**PARTICULATE FIELD DATA**
(continued)

Location ______

Date 1/20/78

Sheet 2 of 2

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. $H_2O$ $\Delta P$ | ORIFICE $\Delta H$ IN. $H_2O$ DESIRED | ORIFICE $\Delta H$ IN. $H_2O$ ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP °F | IMPINGER TEMP °F | STACK PRESS IN. Hg | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | | [illegible]7 | 46:19 | 208.[illegible] | .138 | [illegible] | [illegible] | 72 | 66 | [illegible] | 267 | 45 | | [illegible]3 |
| 11 | | [illegible] | 50 | 211.4 | [illegible] | 1.2 | 1.5 | [illegible] | [illegible] | 7 | 260 | 44 | | 172 |
| 12 | | | 55 | [illegible] | .08 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] |
| Stop | | [illegible]2 | 60 | 217.662 | | | | | | | | | | |
| | | | | 8.864 | | | | | | | | | | |
| | | Total | | 34.130 | | | | 82.923 | ~~[illegible]~~ | | | | | |
| | | | | -.360 | | | | | | | | | | |
| | | | | 33.770 | .118 | 1.122 | | | 75.464 | | | | | 158.077 |
| | | | | | | | | | 61.38[illegible] | | | | | |
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| | | | TOTAL | | | | | | | | | 62.884 | | |

Meter leak check during test: Meter stop Reading start

______ CF ______ Sec ______ in.Hg's ______ ______

______ CF ______ Sec ______ in.Hg's ______ ______

Static Pressure: Port ______ ______ ______

in.$H_2O$ ______ ______ ______

COMMENTS:

.387 CFm to 4" [illegible]

.001 CFm to 2" [illegible]ider

.132 CFm to 3" [illegible]

## PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/26/78
Client:
Run No.: RAC #3
W. O. No.:
Sample Box No.
Plant: CAFB
Operator:
Sampling Location:

---

**FRONT HALF**

Laboratory Results

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. ____ Residue ____ mg

Cyclone and Flask-Acetone Wash Lab No. ____ Residue ____ mg

| Filter No. | Lab No. | Weight Results |
|---|---|---|
| G69 | | 1.51072 g |
| Cyclon. | | 0.41236 g |
| RINSE | | .19160 mg |
| | | 2.11468 mg |

Filter particulate weight 1923.1 mg

FRONT HALF Sub Total ____ mg

**BACK HALF**

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder

TRAIN AS METHOD 8 - SEE SHEET

Lab No.

Collected on 0.22μ Filter ____ mg

Aqueous Residue ____ mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash

Lab No. ____ Residue ____ mg

BACK HALF Sub Total ____ mg

TOTAL WEIGHT ____ mg

**MOISTURE**

| Impingers | I | F |
|---|---|---|
| #1 | 584.70 | 577.60 |
| #2 | 588.38 | 631.42 |
| #3 | 588.90 | 603.81 |

Final Volume 1812.83
Initial Volume 1761.98
Net Volume 50.85

**Silica Gel**

| | | | | |
|---|---|---|---|---|
| Weight after test: | 273.58 | | | |
| Weight before test: | 255.95 | | | |
| Net Weight | 17.63 | | | |
| Container No.: | 1. | 2. | 3. | 4. |

TOTAL WEIGHT-Silica Gel 17.63 gm

TOTAL VOLUME-Impingers 50.85 ml

TOTAL MOISTURE 68.48 gm

Comments:

---

LAB: DATE RECEIVED
DATE REPORTED

ANALYTICAL CHEMIST

HFS/5/77

Location CAFB
Run # RAC #4
Date 1/27/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | .698 | $Vw^{Std}$ | 1.23 |
| Vw (ml) | 26.1 | $Vm^{Std}$ | 26.318 |
| Vm ($Ft^3$) | 27.132 | $9^r$/DSCF | .8520 |
| Tm (°R) | 536.54 | % M | 4.47 |
| Pb ("Hg) | 29.44 | % Dry Gas | 95.53 |
| Mg. Partic. | 1456.66 | M. W. (Wet) | 28.73 |
| % $CO_2$ | 6.4 | D (Lbs./$Ft^3$) | .056 |
| % $O_2$ | 5.3 | % EA | 29.426 |
| % CO | 0 | Vs (fpm) | 496.37 |
| TS (°R) | 688.3 | Qs ($ft^3$) | ~~14221~~ 1422.45 |
| PST ("$H_2O$) | .08 | Wp (lbs. part/hr) | 10.38 |
| $\Delta P^{1/2}$ | .124 | % I | 88.58 |
| Cp | .865 | | |
| TT (min) | 60 | | |
| $A_{noz}$ ($ft^2$) | .00134 | | |
| AST ($ft^2$) | 3.976 | | |

Reproduced from best available copy.

Sheet 1 o. ______

## PARTICULATE FIELD DATA

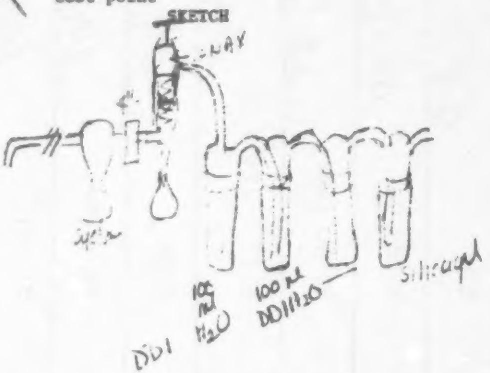
VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

Client CAFB
W. O. No. ______
Plant ______
Run No. ABC #4
Location ______
Date 11/27/78
Operator ______
Sample Box No. ______
Meter Box No. ______
Meter∆H ______
C Factor ______

Pitot Number & Side ______
Pitot tube CP ______
Filter No. 371
Ambient Temp. °F ______
Bar. Press. "Hg ______
Assumed Moisture % ______
Heater Box Setting, °F ______
Nozzle #/Dia., ______
Probe Length ______
Probe Heater Setting ______
Avg.∆P ______ Avg. ∆H ______

SKETCH



| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. H2O ∆P | ORIFICE ∆ H IN. H2 O DESIRED | ORIFICE ∆ H IN. H2 O ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP. °F | IMPINGER TEMP. °F |  | STACK PRESS IN. Hg. | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 |  | 1515 | 0 | 725.536 | .01 .1 | .58 | .58 | 57 | 60 | 5.5 | 327 | 57 | 55 |  | 228 |
| 6 |  |  | 5 |  | .01 .1 | .58 | .58 | 78 | 64 | 6 | 285 | 55 |  |  | 228 |
| 6 |  |  | 10 |  | .01 .1 | .58 | .58 | 80 | 66 | 6.5 | 271 | 54 | 32 |  | 227 |
| 6 |  |  | 15 |  | .012 .16 | .70 | .70 | 82 | 67 | 7.5 | 2[illegible]5 | 54 |  |  | 228 |
|  |  |  | 20 |  | .015 .2 | 1.0 | 1.0 | 84 | 66 | 7.5 | 303 | 54 | 27 |  | 228 |
|  |  |  | 25 |  | .013 .1 | .83 | .83 | 88 | 70 | 7.5 | 308 | 54 | 25 |  | 229 |
|  |  |  | 30 |  | .013 .14 | .72 | .72 | 70 | 70 | 7.5 | 290 | 54 | 22 |  | 228 |
|  |  |  | 35 |  | .01 .3 | .55 | .55 | 88 | 72 | 7.5 | 280 | 54 | 22 |  | 228 |
|  |  |  | 40 |  | .017 .16 | .74 | .74 | 88 | 72 | 8.5 | 315 | 54 | 23 |  | 228 |
|  |  |  | 45 | 27.852 | .01 .1 | .54 | .54 | 88 | 72 | 7.0 | 284 | 53 | 22 |  | 230 |
|  |  |  | 50 |  | .016 .1 | .77 | .77 | 88 | 72 | 8.5 | 285 | 54 | 23 |  | 231 |
|  |  |  |  |  | .013 .16 | .83 | .83 | 88 | 74 | 9.5 | 276 | 55 | 22 |  | 231 |
|  |  |  |  |  |  |  |  | 84.167 | 68.917 |  |  | 54.333 | 815 |  | 228.333 |

Meter leak check: 5.5 60 TOTAL 253.387 .010
Before test: ______ CF ______ Sec ______ in.Hg
After test: ______ CF ______ Sec ______ in.Hg
Static Pressure (PST) Port ______ in.H2O

COMMENTS: .698
B-3 254.4 g
Leak = .010

## PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: Jn. 27 1978
Client:
Run No.: RAC #4
W. O. No.:
Sample Box No.
Plant: CAFB
Operator:
Sampling Location:

**FRONT HALF**

Laboratory Results

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. Residue mg
Cyclone and Flask-Acetone Wash Lab No. Residue mg

| Filter No. | Lab No. | Weight Results |
|---|---|---|
| S-71 | | 1.34237 µg |
| cyclone | | 0.03738 µg |
| | | .07631 mg |
| | | 1.45606 mg |

Filter particulate weight 1379.8 mg
FRONT HALF Sub Total mg

**BACK HALF**

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder
Lab No.
Collected on 0.22µ Filter mg
Aqueous Residue mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash
Lab No. Residue mg
BACK HALF Sub Total mg
TOTAL WEIGHT mg

**MOISTURE**

**Impingers**

Final Volume 218
Initial Volume 200
Net Volume 18 ml

**Silica Gel**

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Weight after test: | 262.5 | | | |
| Weight before test: | 254.4 | | | |
| Net Weight | 8.1 | | | |
| Container No.: | | | | |

TOTAL WEIGHT-Silica Gel 8.1 gm
TOTAL VOLUME-Impingers 18.0 ml
TOTAL MOISTURE 26.1 gm

Comments:

LAB: DATE RECEIVED
DATE REPORTED

ANALYTICAL CHEMIST

HFS/5/77

# NOMOGRAPH SETUP DATA SHEET

CLIENT CAFB

GCA WORK ORDER NO. ______ DATE: 1-25-78

PLANT CAFB / ESSO

SAMPLING LOCATION ______

METER BOX NO. ______ METER BOX $\Delta H$@ 2.104

MOISTURE VOL. % 8% BAR. PRESSURE (PB)(PM) 29.54 in. Hg

STATIC PRESSURE SAMPLING POINT (PST) .08 in. $H_2O$ x 0.735 = .0059

PRESSURE STACK (PS) PB±(PST) = ___ + ___ = 29.55 in. Hg

$PS/_{PM}$ = ___ = 1.00 PITOT TUBE NO. ___

$C_p$ = .865 ; $(C_p/0.85)^2 = (1.017\ )^2 = 1.035$ Cpc ; Cc = C x cpc

$\Delta p$ LOW .01 ; $\Delta p$ AVERAGE .013 ; $\Delta p$ HIGH .017

NOZZLE DIAMETER 5/8 in. ; TS min 169 TS avg 190.2 TS high 197

## K FACTOR CHART

| C | 1.05 | 1.1 | , | 1.11 | | 1.15 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CC | 1.09 | 1.14 | | 1.14 | | 1.19 | | | | |
| TM / TS | 60 | 70 | | 80 | | 90 | | | | |
| 150 | .79 | .81 | | .81 | | .85 | | | | |
| 160 | .79 | .80 | | .80 | | .82 | | | | |
| 170 | .79 | .79 | | .79 | | .84 | | | | |
| 180 | .78 | .78 | | .78 | | .82 | | | | |
| 190 | .78 | .77 | | .77 | | .81 | | | | |
| 200 | .76 | .76 | | .76 | | .80 | | | | |
| 210 | .75 | .76 | | .76 | | .79 | | | | |
| 220 | .75 | .75 | | .75 | | .79 | | | | |
| 230 | .75 | .74 | | .74 | | .78 | | | | |
| 240 | .74 | .74 | | .74 | | .77 | | | | |

K FACTOR REFERENCE ON $\Delta p$ SCALE

Location CAFB
Run # RAC #5
Date 11/27/78

| INPUT | | OUTPUT | |
|---|---|---|---|
| $\overline{\Delta H}$ ($H_2O$) | .552 | $Vw^{Std}$ | 2.54 |
| Vw (ml) | 53.8 | $Vm^{Std}$ | 24.63 |
| Vm ($Ft^3$) | 25.20 | $g^r$/DSCF | .7917 |
| Tm ($^oR$) | 532.28 | % M | 9.346 9.35 |
| Pb ("Hg) | 29.44 | % Dry Gas | 90.65 |
| Mg. Partic. | 1266.25 | M. W. (Wet) | 28.186 |
| % $CO_2$ | 6.4 | D ($^{Lbs.}/Ft^3$) | .0552 |
| % $O_2$ | 5.3 | % EA | 29.43 |
| % CO | 0 | Vs (fpm) | 388.50 |
| TS ($^oR$) | 690.08 | Qs ($ft^3$) | 1053.8 |
| PST ("$H_2O$) | .08 | Wp ($^{lbs.}$part/hr) | 7.18 |
| $\Delta P^{1/2}$ | .096 | % I | ~~111.77~~ 113.1 |
| Cp | .816 | | |
| TT (min) | 60 | | |
| $A_{noz}$ ($ft^2$) | .001364 | | |
| AST ($ft^2$) | 3.976 | | |

Sheet 1 of _______

Client _______

W. O. No. _______

Plant CAFB/EDDO

Run No. RAC #5

Location _______

Date 1/27/78

Operator _______

Sample Box No. 2257

Meter Box No. 2257

Meter ΔH _______

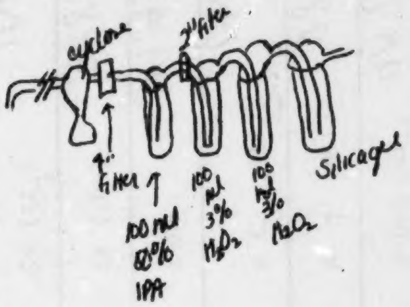
C Factor _______

# PARTICULATE FIELD DATA

**VERY IMPORTANT - FILL IN ALL BLANKS**

Read and record at the start of each test point

SKETCH



Pitot Number & Side _______

Pilot tube CP _______

Filter No. G87

Ambient Temp. °F _______

Bar. Press. "Hg 29.44

Assumed Moisture % _______

Heater Box Setting, °F _______

Nozzle #/Dia., In. _______

Probe Length 3'

Probe Heater Setting _______

Avg. ΔP _______ Avg. ΔH _______

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. H2O ΔP | ORIFICE ΔH IN. H2O DESIRED | ORIFICE ΔH IN. H2O ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP. °F | IMPINGER TEMP. °F | STACK PRESS IN. Hg. | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 1725 | 0 | 253.562 | .01 .1 | .58 | .58 | 58 | 55 | 2 | [illegible] | 47 | | 232 |
| 2 | | | 5 | | .011 .105 | .70 | .70 | 72 | 63 | 2.5 | 312 | 44 | | 234 |
| 3 | | | 10 | | .01 .1 | .55 | .55 | 76 | 60 | 2.5 | 334 | 45 | | 235 |
| 4 | | | 15 | | .0[illegible] .105 | .70 | .70 | 80 | 62 | 2.5 | 331 | 47 | | 236 |
| 5 | | | 20 | | .008 [illegible] | .38 | .38 | 82 | 64 | 2 | 283 | 47 | | 234 |
| 6 | | | 25 | | .01 .1 | .57 | .57 | 83 | 64 | 2.5 | 290 | 50 | | 235 |
| 7 | | | 30 | | .008 .05 | .38 | .37 | 84 | 66 | 2 | [illegible] | 49 | | 234 |
| 8 | | | 35 | | .009 [illegible] | .64 | .61 | 83 | 68 | 2 | 285 | 48 | | 230 |
| 9 | | | 40 | | .01 .1 | .57 | .59 | 85 | 68 | 3.5 | 282 | 48 | | 224 |
| 10 | | | 45 | | .011 .105 | .74 | .74 | 85 | 70 | 4.0 | 269 | 47 | | 207 |
| 11 | | | 55 | | .01 .1 | .72 | .72 | 85 | 70 | 4.0 | 282 | 47 | | 186 |
| | | | | | | | .679 | 81 | 72 | | | | | 170 |
| | | | TOTAL | | 10.87 | | | | | | | | | |

230.08

Meter leak check:

Before test: _______ CF _______ Sec _______ in. Hg ±.11 :.098

After test: _______ CF _______ Sec _______ in. Hg

Static Pressure (PST) Port _______ in. H2O _______

COMMENTS:

SILICA GEL D-1 298.6g.

74.61

I1 586.30

I2 589.98

I3 588.18

64.9

Client [illegible] PARTICULATE FIELD DATA (continued) Sheet ____ of ____

W.O. No. ____

Plant ____ Location ____

Run No. [illegible] Date [illegible]

| POINT | DISTANCE IN INCHES | CLOCK TIME ACTUAL | CLOCK TIME RUN | DRY GAS METER, CF | PITOT IN. $H_2O$ $\Delta P$ | ORIFICE $\Delta H$ IN. $H_2O$ DESIRED | ORIFICE $\Delta H$ IN. $H_2O$ ACTUAL | DRY GAS TEMP. °F INLET | DRY GAS TEMP. °F OUTLET | PUMP VACUUM IN. Hg GAUGE | BOX TEMP °F | IMPINGER TEMP °F | STACK PRESS IN. Hg | STACK TEMP. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | | | 55 | | .005 .07 | .25 .17 | .25 | 86 | 72 | 2 | [illegible] | 47 | | 170 |
| | | | | | | | | | | | | | | |
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| | | | | 4ch1 | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | 60 | 278.763 | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | 0.02091 | | 25.20 | Tot .06 | | .552 | 72.28 | | | 2300B | | | |
| | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | TOTAL | | | | | | | | | | | |

| Meter leak check during test: | Meter stop | Reading start |
|---|---|---|
| ____ CF ____ Sec ____ in.Hg's | ____ | ____ |
| ____ CF ____ Sec ____ in.Hg's | ____ | ____ |
| Pressure: Port | ____ ____ | ____ |
| in.$H_2O$ | ____ ____ | ____ |

COMMENTS: [illegible]

## PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/27/78
Client:
Run No.: RAC#45
W. O. No.:
Sample Box No.
Plant: CAFB/ESSO
Operator:
Sampling Location:

---

**FRONT HALF** — Laboratory Results

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. ______ Residue ______ mg
Cyclone and Flask-Acetone Wash Lab No. ______ Residue ______ mg

| Filter No. | Lab No. | Weight Results |
|---|---|---|
| G 87 | | 1.17512 gm |
| Cyclone | | 0.03176 gm |
| RINSE | | .05930 mg |
| | | 1.26623 mg |

Filter particulate weight 1206.9 mg
FRONT HALF Sub Total ______ mg

**BACK HALF**

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder Lab No. ______
Collected on 0.22µ Filter ______ mg
Aqueous Residue ______ mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash Lab No. ______ Residue ______ mg
BACK HALF Sub Total ______ mg
TOTAL WEIGHT ______ mg

**MOISTURE**

Impingers

| | I Wt | F Wt. | |
|---|---|---|---|
| I1 | 586.30 | 586.95 | |
| I2 | 589.98 | 623.77 | 33.79 |
| I3 | 588.18 | 599.28 | 11.18 |
| | | | 94.92 |

Final Volume ______
Initial Volume ______
Net Volume ______

**Silica Gel**

Weight after test: 257.5
Weight before test: 248.6
Net Weight ______
Container No.: 1. 8.9 2. ______ 3. ______ 4. ______

TOTAL WEIGHT-Silica Gel 8.9 gm
TOTAL VOLUME-Impingers 49.9 ml
TOTAL MOISTURE 53.8 gm

Comments:

LAB: DATE RECEIVED
DATE REPORTED

ANALYTICAL CHEMIST

HPS/5/77

# APPENDIX D

# DATA FROM LABORATORY ANALYSES OF CAFB SAMPLES

TABLE D-1. SAMPLE ABBREVIATION CODE

| Sample code | Sample description |
|---|---|
| PF | Particulate filter |
| 1c, 1 μc | 1 micron cyclone |
| 3c, 3 μc | 3 micron cyclone |
| 10c, 10 μc | 10 micron cyclone |
| PR | Solvent probe rinse |
| XR | XAD-2 resin |
| MR | Solvent module rinse |
| CD | Module condensate |
| CH | Composite of acid module rinse, condensate, and first impinger |
| IC | Composite of second and third impingers |
| RB | Regenerator bed |
| GB | Gasifier bed |
| FR | Fines return |
| RC | Regenerator cyclone |
| MC | Main cyclone |
| SC | Stack cyclone |
| KO | Knockout |
| BB | Boiler back |
| BS | Boiler sides |
| CF, Lig. | Coal feed (Lignite) |
| Lim. | Limestone |

## TABLE D-2. SSMS ANALYSIS OF 10μ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-10C-0-1 0.10586

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 5.3 |
| TH | 15. |
| BI | < 2.3 |
| PB | 62. |
| TL | < 0.38 |
| AU | < 0.099 |
| IR | < 0.15 |
| OS | < 0.17 |
| RE | < 0.11 |
| W | < 0.58 |
| HF | < 2.5 |
| LU | < 1.0 |
| YB | < 0.78 |
| TM | < 0.30 |
| ER | < 1.1 |
| HO | < 0.21 |
| DY | < 2.9 |
| TB | < 0.012 |
| GD | < 1.4 |
| EU | 1.1 |
| SM | 6.0 |
| ND | 13. |
| PR | 4.1 |
| CE | 32. |
| LA | 45. |
| BA | 660. |
| CS | 1.9 |
| I | 2.6 |
| TE | < 1.6 |
| SB | 1.8 |
| SN | 5.7 |
| IN | $ 140. |
| CD | 1.5 |
| PD | < 1.7 |
| RH | < 0.31 |
| RU | < 0.083 |
| MO | 2.4 |
| NB | 27. |
| ZR | 150. |
| Y | 54. |
| SR | 850. |
| RB | 19. |
| BR | 83. |
| SE | < 27. |
| AS | 200. |
| GE | 12. |
| GA | 31. |
| ZN | 660. |
| CU | 97. |
| NI | 46. |
| CO | 21. |
| FE | MC |
| MN | 0.19 (%) |
| CR | 40. |
| V | 91. |
| TI | 0.64 (%) |
| CA | 6.5 (%) |
| K | 0.17 (%) |
| S | MC |
| P | 210. |
| SI | 6.7 (%) |
| AL | MC |
| MG | 0.48 (%) |
| NA | 850. |
| B | 340. |
| BE | 3.6 |

## TABLE D-3. SSMS ANALYSIS OF 3μ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-3C-0-1 0.1003G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 9.8 |
| TH | 20. |
| BI | < 8.4 |
| PB | 50. |
| TL | < 0.15 |
| AU | < 0.18 |
| IR | < 0.28 |
| OS | < 0.31 |
| RE | < 0.20 |
| W | < 0.73 |
| HF | < 2.3 |
| LU | < 0.89 |
| YB | < 0.95 |
| TM | < 0.068 |
| ER | < 0.20 |
| HO | < 0.38 |
| DY | < 0.11 |
| TB | < 0.022 |
| GD | < 0.11 |
| EU | < 0.71 |
| SM | < 2.8 |
| ND | 12. |
| PR | 4.1 |
| CE | 30. |
| LA | 42. |
| BA | 720. |
| CS | 1.3 |
| I | < 0.44 |
| TE | < 0.83 |
| SB | 2.3 |
| SN | 5.3 |
| IN | S 140. |
| CD | 0.98 |
| PD | < 1.6 |
| RH | < 0.050 |
| RU | < 0.15 |
| MO | 2.8 |
| NB | 25. |
| ZR | 190. |
| Y | 36. |
| SR | 0.100(%) |
| RB | 17. |
| BR | 54. |
| SE | < 6.8 |
| AS | 210. |
| GE | < 8.1 |
| GA | 58. |
| ZN | 230. |
| CU | 32. |
| NI | 85. |
| CO | 14. |
| FE | 1.7 (%) |
| MN | 360. |
| CR | 25. |
| V | 96. |
| TI | 0.36 (%) |
| CA | 9.0 (%) |
| K | 0.47 (%) |
| S | 0.90 (%) |
| P | 730. |
| SI | 13. (%) |
| AL | 1.9 (%) |
| MG | 0.74 (%) |
| NA | 0.31 (%) |
| B | 0.11 (%) |
| BE | 2.4 |
| LI | 24. |

## TABLE D-4. SSMS ANALYSIS OF 1µ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-1C-0-1 0.1030G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 5.6 |
| TH | 23. |
| BI | < 9.7 |
| PB | 160. |
| TL | < 0.35 |
| AU | < 0.42 |
| IR | < 0.65 |
| OS | < 0.71 |
| RE | < 0.45 |
| W | < 1.7 |
| HF | < 11. |
| LU | < 2.1 |
| YB | < 1.7 |
| TM | < 0.16 |
| ER | < 3.2 |
| HO | < 0.62 |
| DY | < 4.3 |
| TB | < 0.051 |
| GD | < 1.7 |
| EU | < 1.1 |
| SM | < 6.4 |
| ND | 14. |
| PR | 4.7 |
| CE | 68. |
| LA | 190. |
| BA | 0.25 (%) |
| CS | 1.6 |
| I | < 0.24 |
| TE | < 3.2 |
| SB | 5.1 |
| SN | 8.6 |
| IN | $ 140. |
| CD | 1.8 |
| PD | < 1.2 |
| RH | < 0.11 |
| RU | < 0.35 |
| MO | 5.1 |
| NB | 57. |
| ZR | 320. |
| Y | 83. |
| SR | 0.13 (%) |
| RB | 29. |
| BR | 89. |
| SE | < 22. |
| AS | 470. |
| GE | < 9.8 |
| GA | 120. |
| ZN | 340. |
| CU | 100. |
| NI | 140. |
| CU | 32. |
| FE | 2.2 (%) |
| MN | 450. |
| CR | 65. |
| V | 220. |
| TI | 0.81 (%) |
| CA | 9.3 (%) |
| K | 0.64 (%) |
| S | 2.9 (%) |
| P | 910. |
| SI | 5.1 (%) |
| AL | 1.9 (%) |
| MG | 0.61 (%) |
| NA | 0.16 (%) |
| B | 0.45 (%) |
| BE | 15. |
| LI | 55. |

## TABLE D-5. SSMS ANALYSIS OF PARTICULATE FILTER FROM SASS-1

SAMPLE ID: CAPB#1-PF-A-1 0.0739G (10.96%)

| ELEMENT | VALUE( UG ) |
|---|---|
| U | 0.93 |
| TH | 1.4 |
| BI | 1.5 |
| PB | 15. |
| TL | < 0.22 |
| AU | < 0.010 |
| IR | < 0.016 |
| OS | < 0.018 |
| RE | < 0.011 |
| W | < 0.17 |
| HF | < 0.19 |
| LU | < 0.017 |
| YB | < 0.11 |
| TM | < 0.032 |
| ER | < 0.12 |
| HO | 0.061 |
| DY | 0.45 |
| TB | < 0.002 |
| GD | < 0.15 |
| EU | 0.11 |
| SM | 0.53 |
| ND | 1.5 |
| PR | 0.44 |
| CE | 6.6 |
| LA | 3.6 |
| BA | 70. |
| CS | 0.41 |
| I | < 0.010 |
| TE | < 0.29 |
| SB | 0.71 |
| SN | 1.4 |
| IN | S 14. |
| CD | 3.5 |
| PD | < 0.098 |
| RH | < 0.066 |
| RU | < 0.010 |
| MO | 1.6 |
| NB | 0.30 |
| ZR | 7.4 |
| Y | 1.3 |
| SR | 59. |
| RB | 2.0 |
| BR | 1.3 |
| SE | < 1.1 |
| AS | 7.8 |
| GE | < 0.36 |
| GA | 11. |
| ZN | 36. |
| CU | 14. |
| NI | 7.0 |
| CO | 1.5 |
| FE | 680. |
| MN | 31. |
| CR | 17. |
| V | 9.3 |
| TI | 200. |
| CA | 4.9 (MG) |
| K | 510. |
| S | 2.1 (MG) |
| P | 41. |
| SI | 270. |
| AL | 1.6 (MG) |
| MG | 1000. |
| NA | MC |
| B | 33. |
| BE | 0.16 |
| LI | 0.68 |

## TABLE D-6. SSMS ANALYSIS OF PARTICULATE FILTER BLANK FOR SASS-1 AND SASS-2

SAMPLE ID: CAFB-PFB-A-1 11.56% (305-)

| ELEMENT | VALUE( UG ) |
|---|---|
| U | < 0.025 |
| TH | < 0.036 |
| BI | < 0.011 |
| PB | 2.1 |
| TL | < 0.014 |
| AU | < 0.018 |
| IR | < 0.028 |
| OS | < 0.031 |
| RE | < 0.020 |
| W | < 0.026 |
| HF | < 0.033 |
| LU | < 0.008 |
| YB | < 0.011 |
| TM | < 0.007 |
| ER | < 0.020 |
| HO | < 0.007 |
| DY | < 0.011 |
| TB | < 0.003 |
| GD | < 0.011 |
| EU | < 0.005 |
| SM | < 0.020 |
| ND | < 0.025 |
| PR | < 0.004 |
| CE | 0.049 |
| LA | < 0.006 |
| BA | 32. |
| CS | 0.069 |
| I | 0.096 |
| TE | < 0.014 |
| SB | 0.16 |
| SN | 2.4 |
| IN | $ 14. |
| CD | 0.54 |
| PD | < 0.014 |
| RH | < 0.005 |
| RU | < 0.018 |
| MO | 0.24 |
| NB | 0.012 |
| ZR | 0.54 |
| Y | 0.009 |
| SR | 1.4 |
| RB | 0.35 |
| BR | 1.2 |
| SE | 0.25 |
| AS | 0.67 |
| GE | < 0.056 |
| GA | < 0.100 |
| ZN | 37. |
| CU | 19. |
| NI | 11. |
| CO | 0.24 |
| FE | 92. |
| MN | 3.3 |
| CR | 0.70 |
| V | 0.21 |
| TI | 0.68 |
| CA | 73. |
| K | 36. |
| S | 230. |
| P | 4.4 |
| SI | 170. |
| AL | 16. |
| MG | 35. |
| NA | 1.7 (MG) |
| B | 32. |
| BE | 0.050 |
| LI | 0.13 |

# TABLE D-7. SSMS ANALYSIS OF XAD-2 RESIN FROM SASS-1

SAMPLE ID: CAFB#1-XR-P-1 0.69286

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.084 |
| TH | < 0.12 |
| BI | < 0.038 |
| PB | 1.3 |
| TL | < 0.047 |
| AU | < 0.063 |
| IR | < 0.097 |
| OS | < 0.11 |
| RE | < 0.067 |
| W | < 0.090 |
| HF | < 0.11 |
| LU | < 0.026 |
| YB | < 0.038 |
| TM | < 0.023 |
| ER | < 0.068 |
| HO | < 0.022 |
| DY | < 0.039 |
| TB | < 0.011 |
| GD | < 0.039 |
| EU | < 0.018 |
| SM | < 0.068 |
| ND | < 0.085 |
| PR | < 0.015 |
| CE | < 0.020 |
| LA | < 0.022 |
| BA | < 0.35 |
| CS | < 0.003 |
| I | < 0.058 |
| TE | < 0.049 |
| SB | < 0.034 |
| SN | 0.37 |
| IN | S 21. |
| CD | < 0.061 |
| PD | < 0.049 |
| RH | < 0.017 |
| RU | < 0.063 |
| MO | < 0.058 |
| NB | < 0.007 |
| ZR | < 0.027 |
| Y | < 0.011 |
| SR | 0.96 |
| RB | 0.028 |
| BR | 4.1 |
| SE | < 0.28 |
| AS | 0.052 |
| GE | < 0.023 |
| GA | < 0.009 |
| ZN | 7.3 |
| CU | 12. |
| NI | 7.1 |
| CO | < 0.22 |
| FE | 31. |
| MN | 0.70 |
| CR | 0.42 |
| V | 0.094 |
| TI | < 0.31 |
| CA | 43. |
| K | 22. |
| S | 570. |
| P | 7.5 |
| SI | 65. |
| AL | 9.4 |
| MG | 29. |
| NA | 110. |
| B | 1.4 |
| BE | < 0.006 |
| LI | 0.040 |

TABLE D-8. SSMS ANALYSIS OF XAD-2 RESIN BLANK FOR SASS-1 AND SASS-2

SAMPLE ID: CAFB-XRB-P-1 0.6674G FROM 4.1G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.25 |
| TH | < 0.36 |
| BI | < 0.11 |
| PB | 1.3 |
| TL | < 0.14 |
| AU | < 0.18 |
| IR | < 0.28 |
| OS | < 0.31 |
| RE | < 0.20 |
| W | < 0.26 |
| HF | < 0.33 |
| LU | < 0.077 |
| YB | < 0.11 |
| TM | < 0.068 |
| ER | < 0.20 |
| HO | < 0.066 |
| DY | < 0.11 |
| TB | < 0.031 |
| GD | < 0.11 |
| EU | < 0.052 |
| SM | < 0.20 |
| ND | < 0.25 |
| PR | < 0.044 |
| CE | < 0.059 |
| LA | < 0.064 |
| BA | < 2.1 |
| CS | < 0.010 |
| I | < 0.17 |
| TE | < 0.14 |
| SB | < 0.100 |
| SN | < 0.14 |
| IN | $ 21. |
| CD | < 0.18 |
| PD | < 0.14 |
| RH | < 0.050 |
| RU | < 0.18 |
| MO | < 0.17 |
| NB | < 0.021 |
| ZR | < 0.080 |
| Y | < 0.033 |
| SR | 1.4 |
| RB | 0.12 |
| BR | 12. |
| SE | 0.82 |
| AS | < 0.038 |
| GE | < 0.069 |
| GA | < 0.028 |
| ZN | 6.8 |
| CU | 8.7 |
| NI | 11. |
| CO | 0.16 |
| FE | 16. |
| MN | 2.0 |
| CR | 0.29 |
| V | 0.097 |
| TI | 0.91 |
| CA | 120. |
| K | 120. |
| S | 500. |
| P | 22. |
| SI | 46. |
| AL | 16. |
| MG | 15. |
| NA | 180. |
| B | 0.38 |
| BE | < 0.001 |
| LI | 0.060 |

## TABLE D-9. SSMS ANALYSIS OF COMPOSITE SAMPLE (CH) FROM SASS-1

SAMPLE ID: CAFR#1-CH-0-1 20ML

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.003 |
| TH | < 0.004 |
| BI | < 0.001 |
| PB | 0.016 |
| TL | < 0.002 |
| AU | < 0.002 |
| IR | < 0.004 |
| OS | < 0.004 |
| RE | < 0.002 |
| W | < 0.003 |
| HF | < 0.004 |
| LU | < 0.001 |
| YB | < 0.001 |
| TM | < 0.001 |
| ER | < 0.002 |
| HO | < 0.001 |
| DY | < 0.001 |
| TB | < 0.001 |
| GD | < 0.001 |
| EU | < 0.001 |
| SM | < 0.002 |
| ND | < 0.003 |
| PR | < 0.001 |
| CE | < 0.001 |
| LA | < 0.001 |
| BA | 0.006 |
| CS | < 0.001 |
| I | < 0.002 |
| TE | < 0.002 |
| SB | < 0.001 |
| SN | 0.84 |
| IN | S 1.8 |
| CD | 0.018 |
| PD | < 0.002 |
| RH | < 0.001 |
| RU | < 0.002 |
| MO | < 0.002 |
| NB | < 0.001 |
| ZR | < 0.001 |
| Y | < 0.001 |
| SR | 0.006 |
| RB | 0.001 |
| BR | 0.017 |
| SE | 0.010 |
| AS | 0.003 |
| GE | < 0.001 |
| GA | < 0.001 |
| ZN | 0.32 |
| CU | 0.30 |
| NI | 0.18 |
| CO | 0.006 |
| FE | 2.0 |
| MN | 0.073 |
| CR | 0.15 |
| V | 0.005 |
| TI | 0.008 |
| CA | 81. |
| K | 0.16 |
| S | 57. |
| P | 0.92 |
| SI | 0.30 |
| AL | 0.15 |
| MG | 0.14 |
| NA | 0.77 |
| B | 0.050 |
| BE | 0.000 |
| LI | 0.001 |

## TABLE D-10. SSMS ANALYSIS OF COMPOSITE SAMPLE BLANK (CHB) FROM SASS-1

SAMPLE ID: CAFB#1-CHB-0-1 20ML

| ELEMENT | | VALUE( PPM ) |
|---|---|---|
| U | < | 0.002 |
| TH | < | 0.002 |
| BI | < | 0.001 |
| PB | | 0.[illegible]9 |
| TL | < | 0.001 |
| AU | < | 0.001 |
| IR | < | 0.002 |
| OS | < | 0.002 |
| RE | < | 0.001 |
| W | < | 0.002 |
| HF | < | 0.002 |
| LU | < | 0.001 |
| YB | < | 0.001 |
| TM | < | 0.001 |
| ER | < | 0.001 |
| HO | < | 0.001 |
| DY | < | 0.001 |
| TB | < | 0.001 |
| GD | < | 0.001 |
| EU | < | 0.001 |
| SM | < | 0.001 |
| ND | < | 0.002 |
| PR | < | 0.001 |
| CE | < | 0.001 |
| LA | < | 0.001 |
| BA | < | 0.007 |
| CS | < | 0.001 |
| I | < | 0.001 |
| TE | < | 0.001 |
| SB | < | 0.001 |
| SN | | 0.24 |
| IN | $ | 1.8 |
| CD | | 0.005 |
| PD | < | 0.001 |
| RH | < | 0.002 |
| RU | < | 0.001 |
| MO | < | 0.001 |
| NB | < | 0.001 |
| ZR | < | 0.001 |
| Y | < | 0.001 |
| SR | | 0.002 |
| RB | | 0.001 |
| BR | | 0.12 |
| SE | | 0.004 |
| AS | | 0.003 |
| GE | < | 0.001 |
| GA | < | 0.001 |
| ZN | | 0.11 |
| CU | | 0.023 |
| NI | | 0.020 |
| CO | | 0.003 |
| FE | | 0.22 |
| MN | | 0.005 |
| CR | | 0.003 |
| V | | 0.001 |
| TI | | 0.007 |
| CA | | 3.0 |
| K | | 0.085 |
| S | | 3.6 |
| P | | 0.52 |
| SI | | 0.13 |
| AL | | 0.047 |
| MG | | 0.022 |
| NA | | 1.3 |
| B | | 0.001 |
| BE | < | 0.000 |
| LI | | 0.001 |

## TABLE D-11. SSMS ANALYSIS OF 10μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CAFB#2-10C-0-1 0.1024G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 6.2 |
| TH | 17. |
| BI | < 3.7 |
| PB | 46. |
| TL | < 0.19 |
| AU | < 0.23 |
| IR | < 0.36 |
| OS | < 0.39 |
| RE | < 0.25 |
| W | < 0.93 |
| HF | < 12. |
| LU | < 3.3 |
| YB | < 1.2 |
| TM | < 0.48 |
| ER | < 1.8 |
| HO | < 0.34 |
| DY | < 2.4 |
| TB | < 0.028 |
| GD | < 1.7 |
| EU | < 1.2 |
| SM | < 5.9 |
| ND | < 22. |
| PR | 5.2 |
| CE | 75. |
| LA | 76. |
| BA | 0.14 (%) |
| CS | 1.7 |
| I | 4.5 |
| TE | < 1.8 |
| SB | 8.0 |
| SN | 7.5 |
| IN | $ 140. |
| CD | 0.82 |
| PD | < 2.0 |
| RH | < 0.35 |
| RU | < 0.20 |
| MO | 4.0 |
| NB | 32. |
| ZR | 220. |
| Y | 46. |
| SR | 0.43 (%) |
| RB | 44. |
| BR | 140. |
| SE | < 45. |
| AS | 780. |
| GE | < 14. |
| GA | 74. |
| ZN | 0.24 (%) |
| CU | 110. |
| NI | 53. |
| CO | 18. |
| FE | MC |
| MN | 0.25 (%) |
| CR | 51. |
| V | 210. |
| TI | 0.82 (%) |
| CA | 5.1 (%) |
| K | 0.46 (%) |
| S | 15. (%) |
| P | 930. |
| SI | MC |
| AL | MC |
| MG | 0.98 (%) |
| NA | 0.30 (%) |
| B | 0.25 (%) |
| BE | 1.5 |
| LI | 54. |

## TABLE D-12. SSMS ANALYSIS OF 3μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CAFB#2-3C-0-1 0.1005G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 5.5 |
| TH | 16. |
| BI | < 6.7 |
| PB | 110. |
| TL | < 0.086 |
| AU | < 0.100 |
| IR | < 0.16 |
| OS | < 0.17 |
| RE | < 0.11 |
| W | < 1.2 |
| HF | < 3.9 |
| LU | < 1.5 |
| YB | < 1.1 |
| TM | < 0.039 |
| ER | < 0.79 |
| HO | < 0.43 |
| DY | < 2.2 |
| TB | < 0.013 |
| GD | < 1.3 |
| EU | < 1.1 |
| SM | < 4.5 |
| ND | 9.8 |
| PR | 3.2 |
| CE | 17. |
| LA | 95. |
| BA | 0.23 (%) |
| CS | 1.0 |
| I | < 0.17 |
| TE | < 0.98 |
| SB | 3.6 |
| SN | 4.7 |
| IN | $ 140. |
| CD | 0.77 |
| PD | < 0.89 |
| RH | < 0.028 |
| RU | < 0.087 |
| MO | 2.5 |
| NB | 20. |
| ZR | 190. |
| Y | 20. |
| SR | 0.11 (%) |
| RB | 20. |
| BR | 62. |
| SE | < 28. |
| AS | 120. |
| GE | 8.9 |
| GA | 66. |
| ZN | 190. |
| CU | 72. |
| NI | 48. |
| CO | 16. |
| FE | 1.7 (%) |
| MN | 200. |
| CR | 14. |
| V | 96. |
| TI | 0.37 (%) |
| CA | 9.0 (%) |
| K | 0.27 (%) |
| S | 2.2 (%) |
| P | 230. |
| SI | 4.4 (%) |
| AL | 1.3 (%) |
| MG | 0.23 (%) |
| NA | 0.11 (%) |
| B | 600. |
| BE | 0.94 |
| LI | 14. |

## TABLE D-13. SSMS ANALYSIS OF 1μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CPFB#2-1C-0-1 0.1007G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 3.9 |
| TH | 7.7 |
| BI | < 0.28 |
| PB | 220. |
| TL | < 2.4 |
| AU | < 0.100 |
| IR | < 0.16 |
| OS | < 0.17 |
| RE | < 0.11 |
| W | < 0.86 |
| HF | < 2.6 |
| LU | < 0.50 |
| YB | < 0.58 |
| TM | < 0.45 |
| ER | < 0.78 |
| HO | < 0.22 |
| DY | < 2.2 |
| TB | < 0.012 |
| GD | < 0.75 |
| EU | < 0.40 |
| SM | 1.6 |
| ND | 7.0 |
| PR | 6.1 |
| CE | 47. |
| LA | 67. |
| BA | 0.23 (%) |
| CS | 2.0 |
| I | < 0.25 |
| TE | < 0.98 |
| SB | 13. |
| SN | 13. |
| IN | $ 140. |
| CD | 0.95 |
| PD | < 1.3 |
| RH | < 0.028 |
| RU | < 0.087 |
| MO | 3.6 |
| NB | 56. |
| ZR | 270. |
| Y | 57. |
| SR | 0.16 (%) |
| RB | 20. |
| BR | 42. |
| SE | < 28. |
| AS | 630. |
| GE | 50. |
| GA | 210. |
| ZN | 260. |
| CU | 100. |
| NI | 70. |
| CO | 22. |
| FE | 3.1 (%) |
| MN | 370. |
| CR | 420. |
| V | 290. |
| TI | 0.67 (%) |
| CA | MC |
| K | 0.27 (%) |
| S | 1.2 (%) |
| P | 0.12 (%) |
| SI | 7.0 (%) |
| AL | MC |
| MG | 0.99 (%) |
| NA | 0.30 (%) |
| B | 0.11 (%) |
| BE | 2.6 |
| LI | 14. |

## TABLE D-14. SSMS ANALYSIS OF PARTICULATE FILTER FROM SASS-2

```
SAMPLE ID:   CAFB#2-PF-A-1  0.0438G


          ELEMENT                 VALUE(  UG )


                U                    0.27
               TH                    0.40
               BI                    0.47
               PB                    7.7
               TL                <   0.091
               AU                <   0.006
               IR                <   0.009
               OS                <   0.010
               RE                <   0.061
                W                <   0.072
               HF                <   0.079
               LU                <   0.007
               YB                <   0.041
               TM                <   0.013
               ER                <   0.055
               HO                <   0.036
               DY                <   0.40
               TB                <   0.017
               GD                <   0.074
               EU                    0.022
               SM                    0.15
               ND                    0.89
               PR                    0.14
               CE                    2.0
               LA                    1.1
               BA                   41.
               CS                    0.12
                I                    0.011
               TE                    0.12
               SB                    0.79
               SN                    2.2
               IN                $  14.
               CD                    1.0
               PD                <   0.039
               RH                <   0.009
               RU                <   0.095
               MO                    0.99
               NB                    0.18
               ZR                    1.9
                Y                    0.55
               SR                   53.
               RB                    0.66
               BR                    0.54
               SE                    3.7
               AS                    3.6
               GE                    0.11
               GA                    7.7
               ZN                   16.
               CU                   11.
               NI                    2.0
               CO                    0.23
               FE                  220.
               MN                    9.9
               CR                    6.9
                V                    1.8
               TI                   64.
               CA                    2.9  (MG)
                K                   55.
                S                    1.3  (MG)
                P                   13.
               SI                  100.
               AL                    1.3  (MG)
               MG                  200.
               NA                    1.5  (MG)
                B                   11.
               BE                    0.024
               LI                    0.22
```

## TABLE D-15. SSMS ANALYSIS OF XAD-2 RESIN FROM SASS-2

SAMPLE ID: CAFB#2-XR-P-1 0.6787G FORM 6.5G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.49 |
| TH | < 0.70 |
| BI | < 0.22 |
| PB | 1.3 |
| TL | < 0.27 |
| AU | < 0.36 |
| IR | < 0.56 |
| OS | < 0.61 |
| RE | < 0.38 |
| W | < 0.52 |
| HF | < 0.68 |
| LU | < 0.15 |
| YB | < 0.22 |
| TM | < 0.13 |
| ER | < 0.39 |
| HO | < 0.13 |
| DY | < 0.22 |
| TB | < 0.061 |
| GD | < 0.22 |
| EU | < 0.100 |
| SM | < 0.39 |
| ND | < 0.49 |
| PR | < 0.086 |
| CE | < 0.12 |
| LA | < 0.13 |
| BA | 0.48 |
| CS | < 0.020 |
| I | < 0.34 |
| TE | < 0.28 |
| SB | < 0.20 |
| SN | < 0.28 |
| IN | $ 21. |
| CD | < 0.35 |
| PD | < 0.28 |
| RH | < 0.098 |
| RU | < 0.36 |
| MO | < 0.33 |
| NB | < 0.042 |
| ZR | < 0.16 |
| Y | < 0.065 |
| SR | 1.3 |
| RB | 0.23 |
| BR | 8.2 |
| SE | < 0.19 |
| AS | < 0.075 |
| GE | < 0.13 |
| GA | < 0.055 |
| ZN | 9.4 |
| CU | 12. |
| NI | 20. |
| CO | 0.15 |
| FE | 31. |
| MN | 1.1 |
| CR | 0.54 |
| V | 0.064 |
| TI | 0.89 |
| CA | 82. |
| K | 49. |
| S | 0.58 (%) |
| P | 22. |
| SI | 47. |
| AL | 18. |
| MG | 29. |
| NA | 360. |
| B | 4.2 |
| BE | 0.011 |
| LI | 0.23 |

## TABLE D-16. SSMS ANALYSIS OF COMPOSITE SAMPLE (CH) FROM SASS-2

SAMPLE ID: CAFB#2-CH-0-1 20ML

| ELEMENT | | VALUE( PPM ) |
|---|---|---|
| U | < | 0.008 |
| TH | < | 0.012 |
| BI | < | 0.004 |
| PB | < | 0.008 |
| TL | < | 0.005 |
| AU | < | 0.006 |
| IR | < | 0.009 |
| OS | < | 0.010 |
| RE | < | 0.007 |
| W | < | 0.009 |
| HF | < | 0.011 |
| LU | < | 0.003 |
| YB | < | 0.004 |
| TM | < | 0.002 |
| ER | < | 0.007 |
| HO | < | 0.002 |
| DY | < | 0.004 |
| TB | < | 0.001 |
| GD | < | 0.004 |
| EU | < | 0.002 |
| SM | < | 0.007 |
| ND | < | 0.008 |
| PR | < | 0.001 |
| CE | < | 0.002 |
| LA | < | 0.002 |
| BA | | 0.008 |
| CS | < | 0.001 |
| I | < | 0.006 |
| TE | < | 0.005 |
| SB | < | 0.003 |
| SN | | 1.1 |
| IN | S | 0.72 |
| CD | | 0.045 |
| PD | < | 0.005 |
| RH | < | 0.002 |
| RU | < | 0.006 |
| MO | | 0.023 |
| NB | | 0.002 |
| ZR | < | 0.003 |
| Y | < | 0.001 |
| SR | | 0.004 |
| RB | | 0.001 |
| BR | | 0.024 |
| SE | | 0.059 |
| AS | | 0.002 |
| GE | < | 0.002 |
| GA | < | 0.001 |
| ZN | | 0.18 |
| CU | | 0.29 |
| NI | | 0.19 |
| CO | | 0.005 |
| FE | | 0.74 |
| MN | | 0.036 |
| CR | | 0.12 |
| V | | 0.002 |
| TI | | 0.038 |
| CA | | 0.84 |
| K | | 0.29 |
| S | | 130. |
| P | | 2.4 |
| SI | | 0.59 |
| AL | | 0.22 |
| MG | | 0.27 |
| NA | | 2.1 |
| B | | 0.77 |
| BE | < | 0.001 |
| LI | | 0.005 |

## TABLE D-17. SSMS ANALYSIS OF COMPOSITE SAMPLE BLANK (CHB) FROM SASS-2

SAMPLE ID: CAFR#2-CHB-0-1 20ML

| ELEMENT | VALUE( PPM ) | |
|---|---|---|
| U | < | 0.024 |
| TH | < | 0.034 |
| BI | < | 0.011 |
| PB | < | 0.022 |
| TL | < | 0.013 |
| AU | < | 0.018 |
| IR | < | 0.027 |
| OS | < | 0.030 |
| RE | < | 0.019 |
| W | < | 0.025 |
| HF | < | 0.031 |
| LU | < | 0.007 |
| YB | < | 0.011 |
| TM | < | 0.006 |
| ER | < | 0.019 |
| HO | < | 0.006 |
| DY | < | 0.011 |
| TB | < | 0.003 |
| GD | < | 0.011 |
| EU | < | 0.005 |
| SM | < | 0.019 |
| ND | < | 0.024 |
| PR | < | 0.004 |
| CE | < | 0.006 |
| LA | < | 0.006 |
| BA | < | 0.008 |
| CS | < | 0.001 |
| I | < | 0.016 |
| TE | < | 0.014 |
| SB | < | 0.009 |
| SN | | 1.3 |
| IN | S | 0.72 |
| CD | | 0.039 |
| PD | < | 0.014 |
| RH | < | 0.005 |
| RU | < | 0.018 |
| MO | < | 0.016 |
| NB | < | 0.002 |
| ZR | < | 0.008 |
| Y | < | 0.003 |
| SR | < | 0.004 |
| RB | < | 0.001 |
| BR | | 0.13 |
| SE | < | 0.009 |
| AS | < | 0.004 |
| GE | < | 0.006 |
| GA | < | 0.003 |
| ZN | | 1.0 |
| CU | | 0.076 |
| NI | | 0.38 |
| CO | < | 0.001 |
| FE | | 0.53 |
| MN | | 0.026 |
| CR | | 0.009 |
| V | | 0.002 |
| TI | | 0.021 |
| CA | | 0.85 |
| K | | 0.16 |
| S | | 9.6 |
| P | | 2.1 |
| SI | | 2.3 |
| AL | | 0.22 |
| MG | | 0.21 |
| NA | | 5.9 |
| B | | 0.025 |
| BE | | 0.000 |
| LI | | 0.003 |

## TABLE D-18. SSMS ANALYSIS OF CYCLONE CATCH FROM RAC-1

```
SAMPLE ID:   CAFB-RAL 1 CYCLONE  0.1036G

           ELEMENT              VALUE( PPM )


              U                    4.3
              TH                   8.5
              BI                   0.64
              PB                  22.
              TL                   8.8
              AU               <   0.11
              IR               <   0.18
              OS               <   0.19
              RE                   0.67
              W                    0.32
              HF               <   2.0
              LU               <   0.55
              YB               <   0.84
              TM               <   0.55
              ER               <   0.86
              HO               <   0.057
              DY               <   0.64
              TB               <   0.16
              GD               <   0.39
              EU               <   0.44
              SM                   1.7
              ND                   3.8
              PR                   1.3
              CE                  13.
              LA                  18.
              BA                 250.
              CS                   0.42
              I                    2.2
              TE               <   0.87
              SB                   1.0
              SN                   1.6
              IN               $  68.
              CD                   0.33
              PD               <   0.97
              RH               <   0.12
              RU               <   0.095
              MO                   1.2
              NB                   7.7
              ZR                  87.
              Y                   15.
              SR                 590.
              RB                   7.7
              BR                  17.
              SE                   5.9
              AS                  19.
              GE               <   5.0
              GA                  17.
              ZN                 760.
              CU                  28.
              NI                   0.11 (%)
              CO                   6.0
              FE                   3.4  (%)
              MN                 710.
              CR                  25.
              V                   59.
              TI                   0.22 (%)
              CA                   4.4  (%)
              K                    0.17 (%)
              S                    3.9  (%)
              P                   45.
              SI                   2.0  (%)
              AL                   0.31 (%)
              MG                   0.16 (%)
              NA                 150.
              B                  220.
              BE                   0.51
              LI                   8.1
```

# TABLE D-19. SSMS ANALYSIS OF NEAT FILTER PARTICULATE FROM RAC-1

```
SAMPLE ID:   CAFB-RAC 1-0-1  0.1189G

              ELEMENT             VALUE( PPM )


                 U                <    4.8
                TH                <    9.6
                BI                <    2.9
                PB                    43.
                TL                <    0.15
                AU                <    0.18
                IR                <    0.28
                OS                <    0.30
                RE                <    1.6
                 W                <    1.5
                HF                <    3.5
                LU                <    1.8
                YB                <    0.90
                TM                <    0.57
                ER                <    1.6
                HO                <    0.55
                DY                <    4.2
                TB                <    0.022
                GD                <    1.1
                EU                <    2.0
                SM                     3.9
                ND                    13.
                PR                     5.5
                CE                    29.
                LA                    41.
                BA                   760.
                CS                     1.3
                 I                <    0.60
                TE                <    1.4
                SB                     1.6
                SN                     7.3
                IN                S   59.
                CD                     0.92
                PD                <    1.0
                RH                <    0.049
                RU                <    0.15
                MO                     1.9
                NB                    17.
                ZR                   240.
                 Y                    17.
                SR                   660.
                RB                    17.
                BR                <    5.0
                SE                <    4.6
                AS                     7.5
                GE                <    4.2
                GA                <   37.
                ZN                   100.
                CU                    44.
                NI                    41.
                CO                     4.7
                FE                     1.6  (%)
                MN                   190.
                CR                    17.
                 V                    93.
                TI                     1.2  (%)
                CA                    12.   (%)
                 K                     0.46 (%)
                 S                     0.88 (%)
                 P                   210.
                SI                     9.7  (%)
                AL                     MC
                MG                     0.46 (%)
                NA                     0.13 (%)
                 B                     0.100(%)
                BE                     0.81
                LI                     7.1
```

## TABLE D-20. SSMS ANALYSIS OF NEAT FILTER PARTICULATE FROM RAC-3

SAMPLE ID: CAFH-RAC 3-0-1 0.11076

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 1.7 |
| TH | < 5.1 |
| BI | < 2.2 |
| PB | 65. |
| TL | < 0.22 |
| AU | < 0.27 |
| IR | < 0.42 |
| OS | < 0.46 |
| RE | < 0.29 |
| W | < 2.3 |
| HF | < 0.95 |
| LU | < 0.94 |
| YB | < 0.95 |
| TM | < 0.100 |
| ER | < 2.1 |
| HO | < 0.049 |
| DY | < 2.8 |
| TB | < 0.033 |
| GD | < 0.94 |
| EU | 0.71 |
| SM | 2.9 |
| ND | 9.0 |
| PR | 3.0 |
| CE | 31. |
| LA | 31. |
| BA | 580. |
| CS | 1.0 |
| I | < 0.46 |
| TE | < 1.0 |
| SB | 4.9 |
| SN | 5.5 |
| IN | $ 63. |
| CD | 0.57 |
| PD | < 0.28 |
| RH | < 0.074 |
| RU | < 0.23 |
| MO | 2.0 |
| NB | 13. |
| ZR | 110. |
| Y | 19. |
| SR | 700. |
| RB | 13. |
| BR | 7.6 |
| SE | < 15. |
| AS | 33. |
| GE | < 15. |
| GA | < 78. |
| ZN | 110. |
| CU | 48. |
| NI | 44. |
| CO | 7.2 |
| FE | 1.4 (%) |
| MN | 290. |
| CR | 15. |
| V | 140. |
| TI | 0.31 (%) |
| CA | 6.0 (%) |
| K | 0.41 (%) |
| CL | < 0.062 |
| S | 1.3 (%) |
| P | 590. |
| SI | 12. (%) |
| AL | MC |
| MG | 0.83 (%) |
| NA | MC |
| F | < 0.058 |
| B | 0.16 (%) |

## TABLE D-21. SSMS ANALYSIS OF CAFB LIGNITE

SAMPLE ID: LIGNITE (S/N50010/77) 0.6757G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 0.23 |
| TH | 0.32 |
| BI | 0.20 |
| PB | 9.6 |
| TL | < 0.029 |
| AU | < 0.036 |
| IR | < 0.055 |
| OS | < 0.060 |
| RE | < 0.038 |
| W | 0.100 |
| HF | < 0.12 |
| LU | < 0.031 |
| YB | < 0.090 |
| TM | < 0.013 |
| ER | < 0.039 |
| HO | < 0.006 |
| DY | 0.20 |
| TB | 0.024 |
| GD | 0.061 |
| EU | < 0.015 |
| SM | 0.18 |
| ND | 0.60 |
| PR | 0.14 |
| CE | 1.1 |
| LA | 1.5 |
| BA | 38. |
| CS | 0.046 |
| I | 0.040 |
| TE | 0.075 |
| SB | 0.30 |
| SN | 2.1 |
| IN | $ 21. |
| CD | 0.17 |
| PD | < 0.037 |
| RH | < 0.010 |
| RU | < 0.030 |
| MO | 0.43 |
| NB | 0.64 |
| ZR | 5.9 |
| Y | 0.65 |
| SR | 37. |
| RB | 0.59 |
| BR | 0.23 |
| SE | 2.8 |
| AS | 1.5 |
| GE | 0.20 |
| GA | 2.6 |
| ZN | 13. |
| CU | 15. |
| NI | 23. |
| CO | 0.50 |
| FE | 0.19 (%) |
| MN | 22. |
| CR | 2.7 |
| V | 14. |
| TI | 230. |
| CA | 0.17 (%) |
| K | 92. |
| S | 0.23 (%) |
| P | 42. |
| SI | 1.3 (%) |
| AL | 0.23 (%) |
| MG | 130. |
| NA | 180. |
| B | 21. |
| BE | 0.030 |
| LI | 0.82 |

# TABLE D-22. SSMS ANALYSIS OF CAFB LIMESTONE

SAMPLE ID: LIMESTONE (LS2) 0.1324G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.37 |
| TH | < 0.53 |
| BI | < 0.23 |
| PB | 12. |
| TL | < 0.27 |
| AU | < 0.33 |
| IR | < 0.51 |
| OS | < 0.55 |
| RE | < 0.35 |
| W | < 0.24 |
| HF | < 1.2 |
| LU | < 0.29 |
| YB | < 0.21 |
| TM | < 0.12 |
| ER | < 0.36 |
| HO | < 0.059 |
| DY | < 0.20 |
| TB | < 0.040 |
| GD | < 0.20 |
| EU | < 0.14 |
| SM | < 0.43 |
| ND | < 0.30 |
| PR | 0.22 |
| CE | 0.42 |
| LA | 1.8 |
| BA | 160. |
| CS | 0.052 |
| I | 4.5 |
| TE | < 0.25 |
| SB | 0.96 |
| SN | 4.7 |
| IN | $ 110. |
| CD | < 0.059 |
| PD | < 0.34 |
| RH | < 0.089 |
| RU | < 0.28 |
| MO | 0.48 |
| NB | < 0.13 |
| ZR | 1.2 |
| Y | 0.52 |
| SR | 210. |
| RB | 2.1 |
| BR | < 18. |
| SE | < 4.3 |
| AS | < 0.079 |
| GE | < 0.11 |
| GA | < 0.048 |
| ZN | 2.1 |
| CU | 4.7 |
| NI | 14. |
| CO | 0.58 |
| FE | 0.15 (%) |
| MN | 8.8 |
| CR | 0.76 |
| V | 6.4 |
| TI | 80. |
| CA | 16. (%) |
| K | 220. |
| S | 530. |
| P | 39. |
| SI | 430. |
| AL | 130. |
| MG | 0.22 (%) |
| NA | 110. |
| B | 17. |
| BE | 0.012 |
| LI | 0.086 |

## TABLE D-23. SSMS ANALYSIS OF CAFB FINES RETURN

SAMPLE ID: CAFB FINES RET 0.0769G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 5.1 |
| TH | 10. |
| BI | < 0.093 |
| PB | 27. |
| TL | < 0.11 |
| AU | < 0.14 |
| IR | < 0.21 |
| OS | < 0.23 |
| RE | < 0.14 |
| W | < 0.54 |
| HF | < 2.5 |
| LU | < 1.4 |
| YB | < 0.70 |
| TM | < 0.14 |
| ER | < 1.0 |
| HO | 0.20 |
| DY | < 2.8 |
| TB | < 0.016 |
| GD | < 0.98 |
| EU | 0.52 |
| SM | < 3.4 |
| ND | 9.1 |
| PR | 4.1 |
| CE | 44. |
| LA | 44. |
| BA | 910. |
| CS | 1.9 |
| I | 0.45 |
| TE | < 0.74 |
| SB | 3.3 |
| SN | 5.5 |
| IN | $ 190. |
| CD | 0.45 |
| PD | < 0.79 |
| RH | < 0.21 |
| RU | < 0.11 |
| MO | 2.9 |
| NB | < 37. |
| ZR | 180. |
| Y | 26. |
| SR | 900. |
| RB | 26. |
| BR | 110. |
| SE | < 19. |
| AS | 270. |
| GE | < 2.9 |
| GA | 21. |
| ZN | < 0.041 |
| CU | 47. |
| NI | 21. |
| CO | 10. |
| FE | 4.1 (%) |
| MN | 260. |
| CR | 59. |
| V | 120. |
| TI | 0.87 (%) |
| CA | MC |
| K | 0.35 (%) |
| S | 0.94 (%) |
| P | 540. |
| SI | MC |
| AL | MC |
| MG | 0.50 (%) |
| NA | 640. |
| B | 160. |
| BE | 0.30 |
| LI | 3.1 |

## TABLE D-24. SSMS ANALYSIS OF CAFB BOILER BACK

SAMPLE ID: CAFB BOILER BACK 0.0961G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 4.1 |
| TH | 16. |
| BI | < 0.074 |
| PB | 29. |
| TL | < 0.85 |
| AU | < 0.11 |
| IR | < 0.17 |
| OS | < 0.18 |
| RE | < 0.12 |
| W | < 0.90 |
| HF | < 5.4 |
| LU | < 0.77 |
| YB | < 0.43 |
| TM | < 0.33 |
| ER | < 1.7 |
| HO | < 0.45 |
| DY | < 2.2 |
| TB | < 0.013 |
| GD | < 0.67 |
| EU | < 0.77 |
| SM | < 4.7 |
| ND | 15. |
| PR | 4.5 |
| CE | 35. |
| LA | 49. |
| BA | 430. |
| CS | 3.0 |
| I | < 0.12 |
| TE | < 0.83 |
| SB | 1.8 |
| SN | 6.3 |
| IN | $ 150. |
| CD | 0.77 |
| PD | < 1.3 |
| RH | < 0.029 |
| RU | < 0.091 |
| MO | 1.9 |
| NB | 59. |
| ZR | 200. |
| Y | 30. |
| SR | 0.11 (%) |
| RB | 21. |
| BR | 46. |
| SE | < 15. |
| AS | 120. |
| GE | < 4.8 |
| GA | 34. |
| ZN | 62. |
| CU | 75. |
| NI | 50. |
| CO | 5.7 |
| FE | 3.3 (%) |
| MN | 210. |
| CR | 25. |
| V | 100. |
| TI | 0.38 (%) |
| CA | 7.1 (%) |
| K | 0.51 (%) |
| S | 0.75 (%) |
| P | 230. |
| SI | MC |
| AL | MC |
| MG | 0.35 (%) |
| NA | 960. |
| B | 210. |
| BE | 0.49 |
| LI | 14. |

## TABLE D-25. SSMS ANALYSIS OF CAFB BOILER SIDES

SAMPLE ID: CAFB BOILER SIDES 0.09826

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 14. |
| TH | 20. |
| BI | < 0.72 |
| PB | 71. |
| TL | < 1.5 |
| AU | < 0.19 |
| IR | < 0.29 |
| OS | < 0.31 |
| RE | < 0.20 |
| W | < 1.6 |
| HF | < 39. |
| LU | < 1.3 |
| YB | < 1.4 |
| TM | < 0.069 |
| ER | < 2.1 |
| HO | < 0.78 |
| DY | < 5.4 |
| TB | < 0.023 |
| GD | < 1.9 |
| EU | < 1.0 |
| SM | < 5.7 |
| ND | 18. |
| PR | 5.7 |
| CE | 60. |
| LA | 85. |
| BA | 0.11 (%) |
| CS | 5.3 |
| I | < 0.63 |
| TE | < 2.5 |
| SB | 6.8 |
| SN | 12. |
| IN | $ 150. |
| CD | 4.0 |
| PD | < 6.7 |
| RH | < 0.59 |
| RU | < 0.16 |
| MO | 31. |
| NB | 73. |
| ZR | 640. |
| Y | 51. |
| SR | 0.11 (%) |
| RB | 36. |
| BR | 79. |
| SE | < 9.7 |
| AS | 370. |
| GE | < 23. |
| GA | 59. |
| ZN | 100. |
| CU | 92. |
| NI | 0.14 (%) |
| CO | 28. |
| FE | MC |
| MN | 0.20 (%) |
| CR | 120. |
| V | 290. |
| TI | 2.1 (%) |
| CA | MC |
| K | 0.48 (%) |
| S | 0.70 (%) |
| P | 410. |
| SI | MC |
| AL | MC |
| MG | 0.70 (%) |
| NA | 830. |
| B | 280. |
| BE | 0.59 |
| LI | 25. |

## TABLE D-26. SSMS ANALYSIS OF CAFB STACK KNOCKOUT

SAMPLE ID: CAFB STACK KO 0.0880G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 9.3 |
| TH | 37. |
| BI | < 0.67 |
| PB | 120. |
| TL | < 1.9 |
| AU | < 0.35 |
| IR | < 0.54 |
| OS | < 0.59 |
| RE | < 0.37 |
| W | < 1.4 |
| HF | < 13. |
| LU | < 1.7 |
| YB | < 2.7 |
| TM | < 1.1 |
| ER | < 3.1 |
| HO | < 1.0 |
| DY | < 7.5 |
| TB | < 0.042 |
| GD | < 1.8 |
| EU | < 1.8 |
| SM | < 7.5 |
| ND | 34. |
| PR | 11. |
| CE | 160. |
| LA | 110. |
| BA | 0.15 (%) |
| CS | 6.8 |
| I | < 1.2 |
| TE | < 2.7 |
| SB | 4.4 |
| SN | 14. |
| IN | $ 160. |
| CD | 2.6 |
| PD | < 2.0 |
| RH | < 0.095 |
| RU | < 0.29 |
| MO | 4.2 |
| NB | 47. |
| ZR | 330. |
| Y | 48. |
| SR | 0.11 (%) |
| RB | 66. |
| BR | 100. |
| SE | < 36. |
| AS | 120. |
| GE | < 7.4 |
| GA | 79. |
| ZN | 140. |
| CU | 120. |
| NI | 220. |
| CO | 18. |
| FE | 1.8 (%) |
| MN | 370. |
| CR | 62. |
| V | 320. |
| TI | 1.1 (%) |
| CA | 9.4 (%) |
| K | 1.6 (%) |
| S | 1.7 (%) |
| P | 760. |
| SI | MC |
| AL | MC |
| MG | 0.43 (%) |
| NA | 0.100(%) |
| B | 0.12 (%) |
| AG | 1.6 |
| LI | 81. |

## TABLE D-27. SSMS ANALYSIS OF CAFB STACK CYCLONE

SAMPLE ID: CAFB STACK CYLCONE 0.1004G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 6.6 |
| TH | 19. |
| BI | < 2.0 |
| PB | 34. |
| TL | < 0.14 |
| AU | < 0.17 |
| IR | < 0.27 |
| OS | < 0.29 |
| RE | < 0.18 |
| W | < 1.0 |
| HF | < 9.4 |
| LU | < 1.8 |
| YB | < 1.4 |
| TM | < 0.75 |
| ER | < 2.7 |
| HO | 0.51 |
| DY | 5.3 |
| TB | < 0.021 |
| GD | < 2.5 |
| EU | 0.95 |
| SM | < 8.9 |
| ND | 17. |
| PR | 7.2 |
| CE | 56. |
| LA | 110. |
| BA | 680. |
| CS | 1.2 |
| I | 0.83 |
| TE | < 0.95 |
| SB | 3.1 |
| SN | 3.5 |
| IN | $ 130. |
| CD | 1.0 |
| PD | < 1.0 |
| RH | < 0.19 |
| RU | < 0.15 |
| MO | 2.6 |
| NB | 47. |
| ZR | 230. |
| Y | 68. |
| SR | 0.12 (%) |
| RB | 42. |
| BR | 73. |
| SE | < 18. |
| AS | 190. |
| GE | < 5.6 |
| GA | 39. |
| ZN | < 59. |
| CU | 61. |
| NI | 56. |
| CO | 13. |
| FE | 2.8 (%) |
| MN | 620. |
| CR | 31. |
| V | 160. |
| TI | 1.1 (%) |
| CA | 6.7 (%) |
| K | 0.82 (%) |
| S | 0.43 (%) |
| P | 690. |
| SI | MC |
| AL | MC |
| MG | 0.64 (%) |
| NA | 0.27 (%) |
| B | 590. |
| BE | 1.1 |
| LI | 68. |

# TABLE D-28. SSMS ANALYSIS OF CAFB REGENERATOR CYCLONE

SAMPLE ID: CAFB REG CYCLONE 0.0888G

| ELFMENT | VALUE( PPM ) |
|---|---|
| U | 8.9 |
| TH | 24. |
| BI | < 0.45 |
| PB | 53. |
| TL | < 1.3 |
| AU | < 0.12 |
| IR | < 0.18 |
| OS | < 0.20 |
| RE | < 0.12 |
| W | < 0.47 |
| HF | < 8.7 |
| LU | < 1.7 |
| YB | < 0.92 |
| TM | < 0.36 |
| ER | < 1.8 |
| HO | 0.98 |
| DY | < 3.8 |
| TB | < 0.014 |
| GD | < 1.7 |
| EU | 1.2 |
| SM | < 6.0 |
| ND | 16. |
| PR | 6.9 |
| CE | 53. |
| LA | 38. |
| BA | 0.14 (%) |
| CS | 2.3 |
| I | 2.2 |
| TE | < 0.90 |
| SB | 3.0 |
| SN | 3.7 |
| IN | $ 160. |
| CD | 1.3 |
| PD | < 1.5 |
| RH | < 0.37 |
| RU | < 0.098 |
| MO | 2.8 |
| NB | 32. |
| ZR | 510. |
| Y | 64. |
| SR | 0.100(%) |
| RB | 16. |
| BR | 70. |
| SE | < 32. |
| AS | 710. |
| GE | < 6.8 |
| GA | 52. |
| ZN | 67. |
| CU | 57. |
| NI | 54. |
| CO | 12. |
| FE | 1.9 (%) |
| MN | 230. |
| CR | 48. |
| V | 180. |
| TI | 0.41 (%) |
| CA | 7.7 (%) |
| K | 0.100(%) |
| S | 2.5 (%) |
| P | 250. |
| SI | 7.9 (%) |
| AL | MC |
| MG | 0.56 (%) |
| NA | 0.100(%) |
| B | 400. |
| BE | 1.1 |
| LI | 8.4 |

## TABLE D-29. SSMS ANALYSIS OF CAFB GASIFIER BED

SAMPLE ID: CAFB GAS BED #1179 0.09496

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.74 |
| TH | < 1.0 |
| BI | < 0.44 |
| PB | < 2.8 |
| TL | < 0.54 |
| AU | < 0.65 |
| IR | < 1.0 |
| OS | < 1.1 |
| RE | < 0.69 |
| W | < 0.46 |
| HF | < 2.3 |
| LU | < 0.56 |
| YB | < 0.41 |
| TM | < 0.24 |
| ER | < 0.70 |
| HO | < 0.12 |
| DY | < 0.40 |
| TB | < 0.078 |
| GD | < 0.40 |
| EU | < 0.28 |
| SM | < 0.84 |
| ND | < 0.58 |
| PR | < 0.86 |
| CE | 9.7 |
| LA | 14. |
| BA | 150. |
| CS | 0.60 |
| I | < 0.13 |
| TE | < 0.49 |
| SB | 23. |
| SN | 19. |
| IN | $ 190. |
| CD | < 0.12 |
| RH | < 0.18 |
| RU | < 0.54 |
| MO | < 0.33 |
| NB | 12. |
| ZR | 110. |
| Y | 17. |
| SR | 290. |
| RB | 15. |
| BR | 72. |
| SE | < 48. |
| AS | 720. |
| GE | < 15. |
| GA | 47. |
| ZN | 67. |
| CU | 40. |
| NI | 36. |
| CO | 9.1 |
| FE | 2.5 (%) |
| MN | 180. |
| CR | 11. |
| V | 100. |
| TI | 0.18 (%) |
| CA | MC |
| K | 0.56 (%) |
| S | 3.2 (%) |
| P | 260. |
| SI | MC |
| AL | 0.41 (%) |
| MG | 1.4 (%) |
| NA | 390. |
| B | 960. |
| BE | 0.77 |
| LI | 25. |

## TABLE D-30. SSMS ANALYSIS OF CAFB REGENERATOR BED

SAMPLE ID: CAFB REG BED #1101 0.08656

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | 1.1 |
| TH | 2.3 |
| BI | < 0.083 |
| PB | 2.4 |
| TL | < 0.100 |
| AU | < 0.12 |
| IR | < 0.19 |
| OS | < 0.20 |
| RE | < 0.13 |
| W | < 0.24 |
| HF | < 1.5 |
| LU | < 0.100 |
| YB | < 0.077 |
| TM | < 0.25 |
| ER | < 0.13 |
| HO | < 0.12 |
| DY | < 0.44 |
| TB | < 0.015 |
| GD | < 0.42 |
| EU | < 0.052 |
| SM | < 0.16 |
| ND | 2.0 |
| PR | 0.47 |
| CE | 6.8 |
| LA | 7.3 |
| BA | 130. |
| CS | 0.45 |
| I | 0.20 |
| TE | < 0.091 |
| SB | 6.1 |
| SN | 9.8 |
| IN | S 170. |
| CD | 0.041 |
| PD | < 1.0 |
| RH | < 0.18 |
| RU | < 0.100 |
| MO | 1.3 |
| NB | 8.2 |
| ZR | 35. |
| Y | 4.4 |
| SR | 220. |
| RB | 29. |
| BR | 36. |
| SE | < 6.2 |
| AS | 240. |
| GE | 5.3 |
| GA | 18. |
| ZN | 24. |
| CU | 21. |
| NI | 18. |
| CO | 3.2 |
| FE | 0.36 (%) |
| MN | 76. |
| CR | 4.2 |
| V | 38. |
| TI | 0.23 (%) |
| CA | MC |
| K | 0.31 (%) |
| S | 0.30 (%) |
| P | 85. |
| SI | 3.2 (%) |
| AL | 3.0 (%) |
| MG | 0.48 (%) |
| NA | 0.11 (%) |
| B | 140. |
| BE | 0.20 |
| LI | 16. |

## TABLE D-31. SSMS ANALYSIS OF CAFB OIL FEED

SAMPLE ID: FOS OIL 0.8356G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.049 |
| TH | < 0.071 |
| BI | 0.12 |
| PB | 11. |
| TL | < 0.028 |
| AU | < 0.037 |
| IR | < 0.057 |
| OS | < 0.062 |
| RE | < 0.034 |
| W | < 0.052 |
| HF | < 0.065 |
| LU | < 0.015 |
| YB | < 0.022 |
| TM | < 0.014 |
| ER | < 0.040 |
| HO | < 0.013 |
| DY | < 0.023 |
| TB | < 0.006 |
| GD | < 0.023 |
| EU | < 0.010 |
| SM | < 0.040 |
| ND | < 0.050 |
| PR | < 0.009 |
| CE | < 0.012 |
| LA | < 0.013 |
| BA | 0.41 |
| CS | 0.006 |
| I | 0.067 |
| TE | < 0.029 |
| SB | 0.15 |
| SN | 0.45 |
| IN | > 17. |
| CD | 0.82 |
| PD | < 0.029 |
| RH | < 0.23 |
| RU | < 0.037 |
| MO | 0.79 |
| NB | 0.024 |
| ZR | 0.045 |
| Y | < 0.007 |
| SR | 0.38 |
| RB | 0.093 |
| BR | 0.28 |
| SE | < 0.019 |
| AS | 1.3 |
| GE | < 0.014 |
| GA | < 0.006 |
| ZN | 48. |
| CU | 28. |
| NI | 97. |
| CO | 0.67 |
| FE | 33. |
| MN | 2.3 |
| CR | 0.98 |
| V | 49. |
| TI | 0.32 |
| CA | 83. |
| K | 99. |
| S | 0.42 (%) |
| P | 15. |
| SI | 110. |
| AL | 31. |
| MG | 51. |
| NA | 150. |
| F | 0.11 |
| BE | 0.001 |
| LI | 0.34 |

## TABLE D-32. SSMS ANALYSIS OF CAFB BITUMEN

SAMPLE ID: BITUMEN 0.9791G

| ELEMENT | VALUE( PPM ) |
|---|---|
| U | < 0.060 |
| TH | < 0.087 |
| BI | < 0.027 |
| PB | 3.7 |
| TL | < 0.034 |
| AU | < 0.045 |
| IR | < 0.069 |
| OS | < 0.075 |
| RE | < 0.047 |
| W | < 0.064 |
| HF | < 0.079 |
| LU | < 0.019 |
| YB | < 0.027 |
| TM | < 0.016 |
| ER | < 0.048 |
| HO | < 0.016 |
| DY | < 0.028 |
| TB | < 0.007 |
| GD | < 0.028 |
| EU | < 0.012 |
| SM | < 0.048 |
| ND | < 0.060 |
| PR | < 0.011 |
| CE | 0.040 |
| LA | < 0.016 |
| BA | 1.4 |
| CS | 0.007 |
| I | < 0.041 |
| TE | < 0.035 |
| SB | 0.091 |
| SN | 0.76 |
| IN | $ 15. |
| CD | 0.24 |
| PD | < 0.035 |
| RH | < 0.012 |
| RU | < 0.044 |
| MO | 0.23 |
| NB | 0.014 |
| ZR | < 0.019 |
| Y | < 0.008 |
| SR | 0.33 |
| RB | 0.056 |
| BR | < 0.059 |
| SE | 1.3 |
| AS | 4.6 |
| GE | < 0.017 |
| GA | 0.056 |
| ZN | 110. |
| CU | 20. |
| NI | 110. |
| CO | 0.58 |
| FE | 40. |
| MN | 2.0 |
| CR | 1.2 |
| V | 130. |
| TI | 0.39 |
| CA | 59. |
| K | 24. |
| S | 0.28 (%) |
| P | 18. |
| SI | 140. |
| AL | 11. |
| MG | 29. |
| NA | 19. |
| B | 1.9 |
| BE | 0.016 |
| LI | 0.53 |

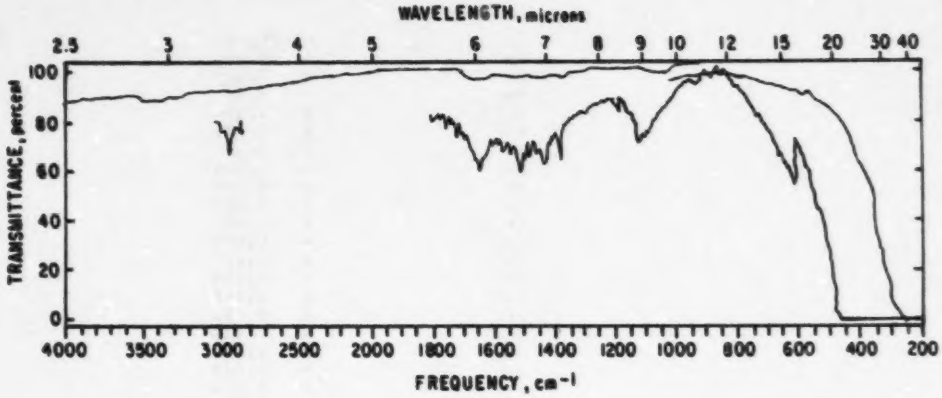

Figure D-1. IR spectrum of 10μ cyclone catch from SASS-1. Content of spectrum is less than or equal to that of blank.

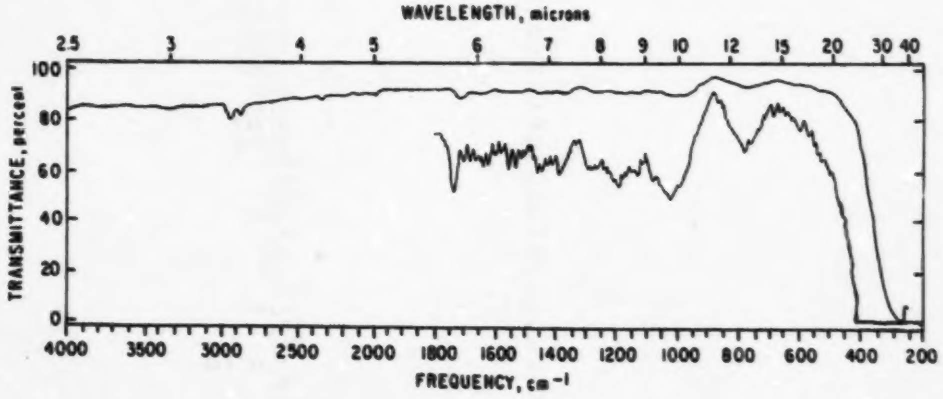

Figure D-2. IR spectrum of 3μ cyclone catch from SASS-1. Peaks indicate saturated esters; possible aryl or unsaturated esters or ethers, organosilicon compounds.

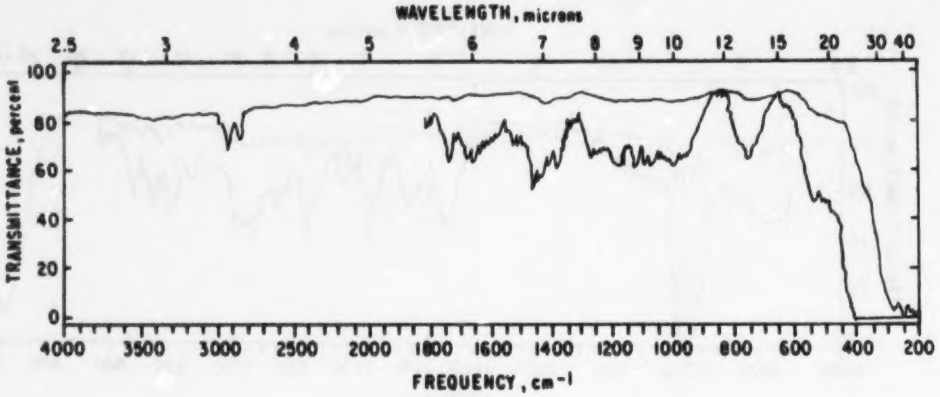

Figure D-3. IR spectrum of $1\mu$ cyclone catch from SASS-1. Peaks indicate saturated esters and hydrocarbons; possible aryl or unsaturated esters or ethers.

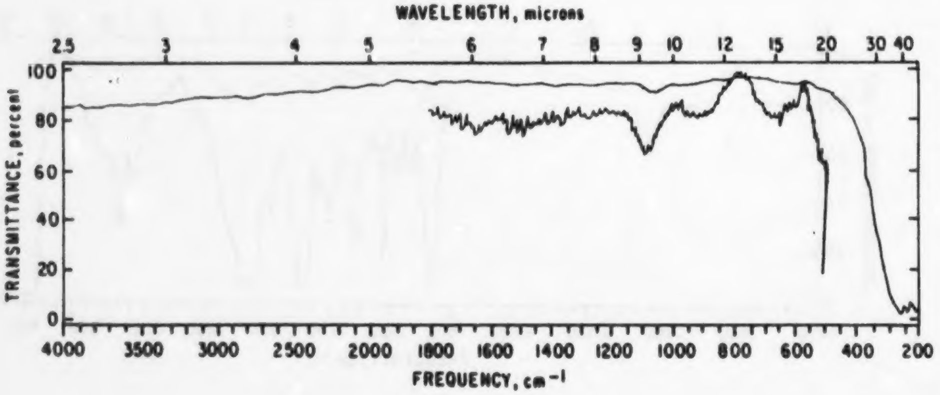

Figure D-4. IR spectrum of particulate filter from SASS-1. Content of spectrum is less than or equal to that of blank.

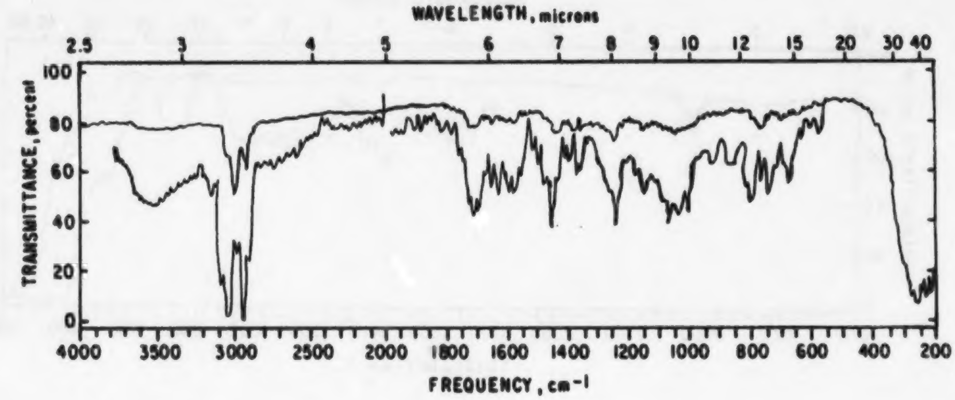

Figure D-5. IR spectrum of condensate extract from SASS-1. Major peaks indicate aliphatic hydrocarbons, esters, ketones; possible ethers, substituted aromatics, nitrocompounds and organosilicon compounds.

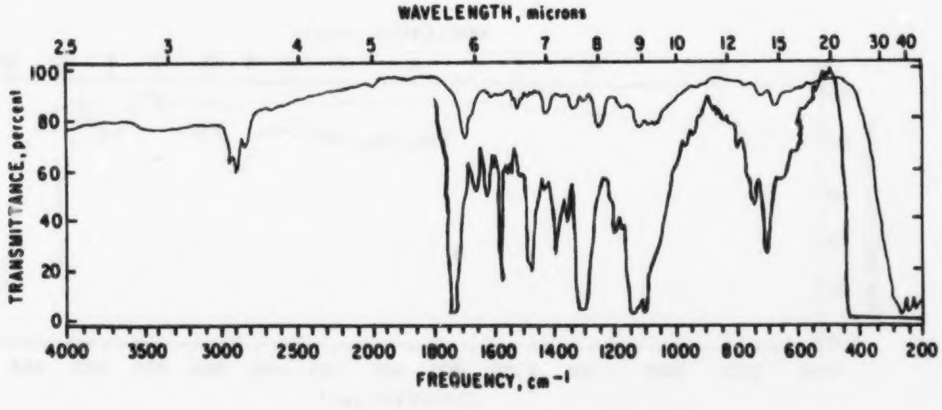

Figure D-6. IR spectrum of XAD-2 resin from SASS-1. Major peaks indicate esters, saturated hydrocarbons; possible ethers and nitrosubstituted compounds.

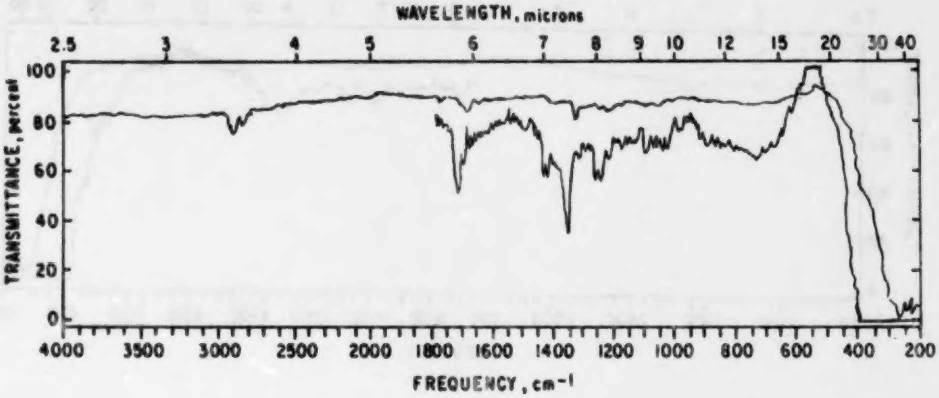

Figure D-7. IR spectrum of module rinse from SASS-1. Peaks indicate esters and aliphatic ethers.

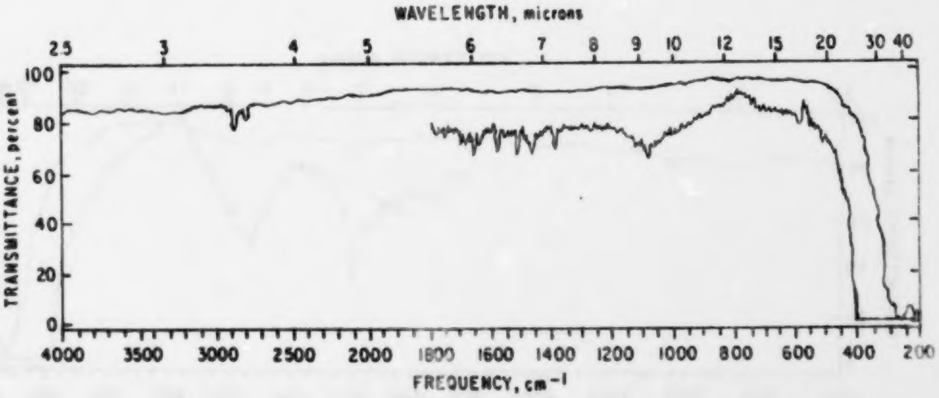

Figure D-8. IR spectrum of probe rinse from SASS-1. Content of spectrum is less than or equal to that of blank.

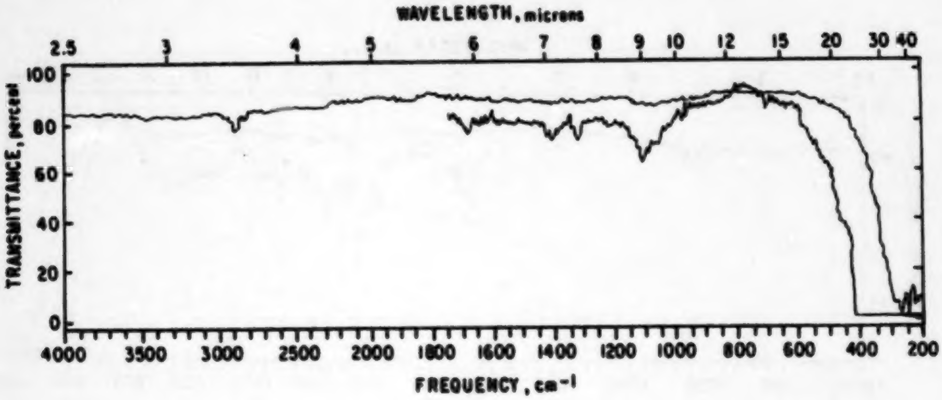

Figure D-9. IR spectrum of 10μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

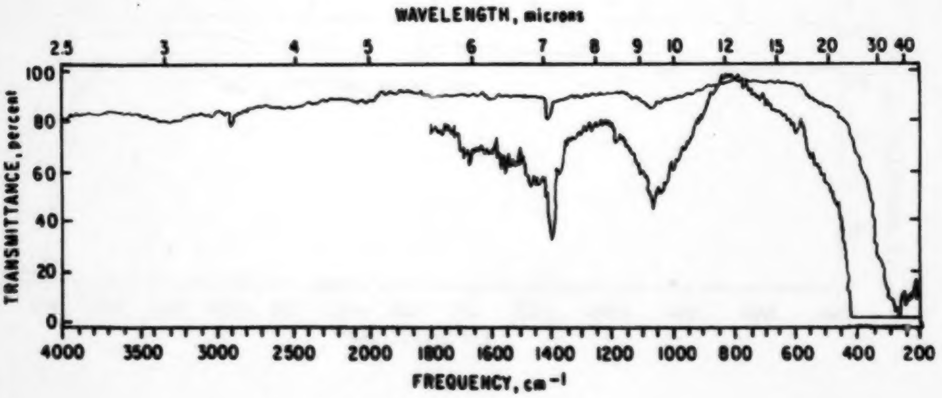

Figure D-10. IR spectrum of 3μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

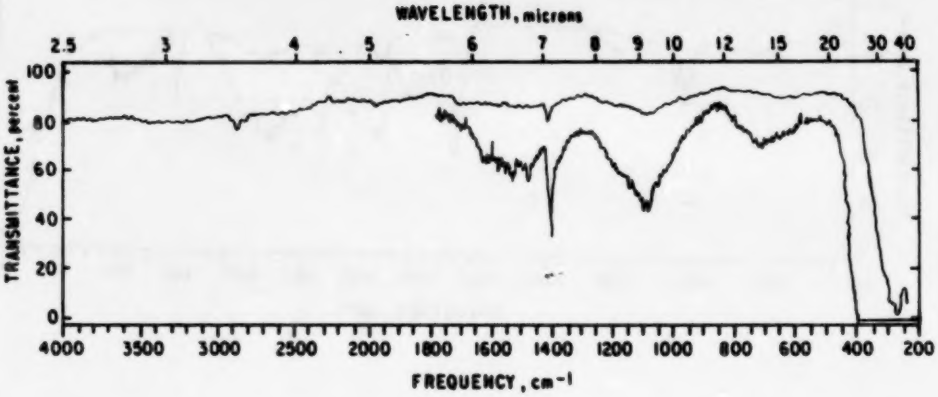

Figure D-11. IR spectrum of 1μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

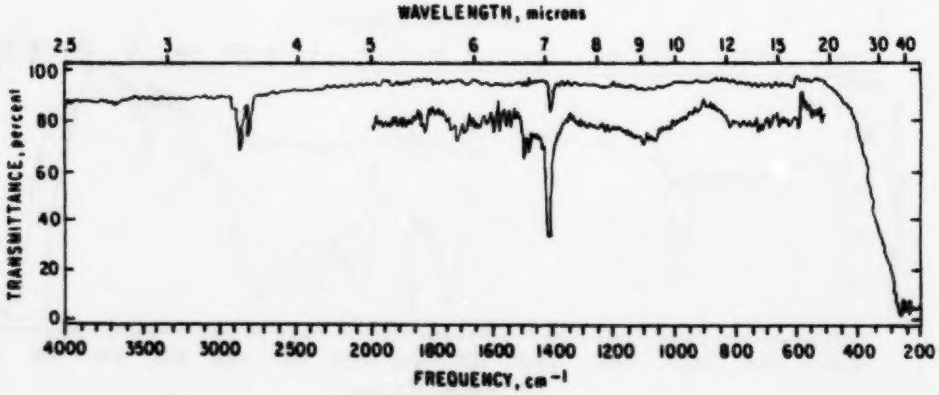

Figure D-12. IR spectrum of particulate filter from SASS-2. Content of spectrum is less than or equal to that of blank.

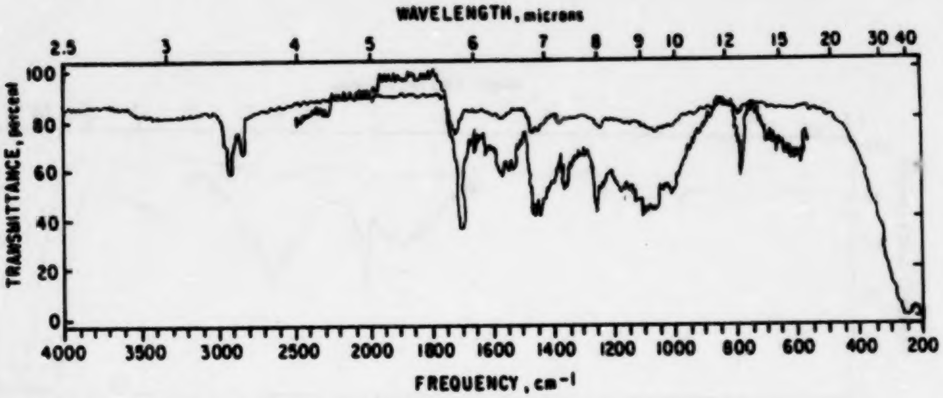

Figure D-13. IR spectrum of probe rinse from SASS-2. Major peaks indicate saturated hydrocarbons, esters and aryl esters; possible substituted aromatics and aliphatic ethers.

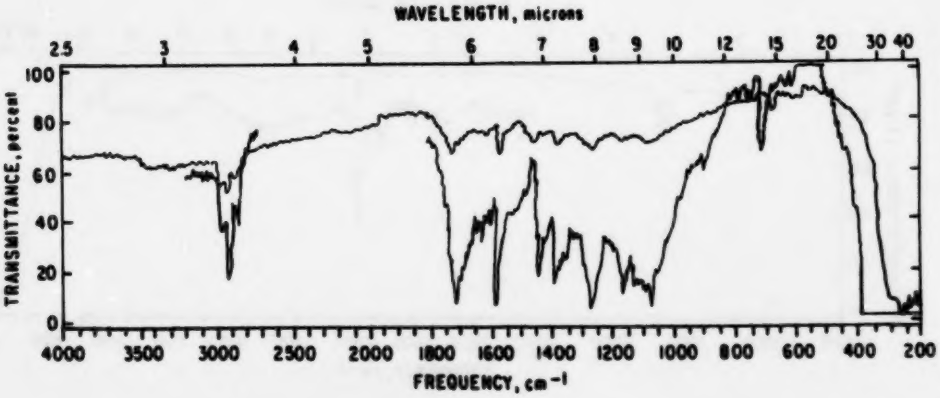

Figure D-14. IR spectrum of XAD-2 resin from SASS-2. Major peaks indicate aryl or unsaturated esters, ketones, hydrocarbons; possible ethers and nitrocompounds.

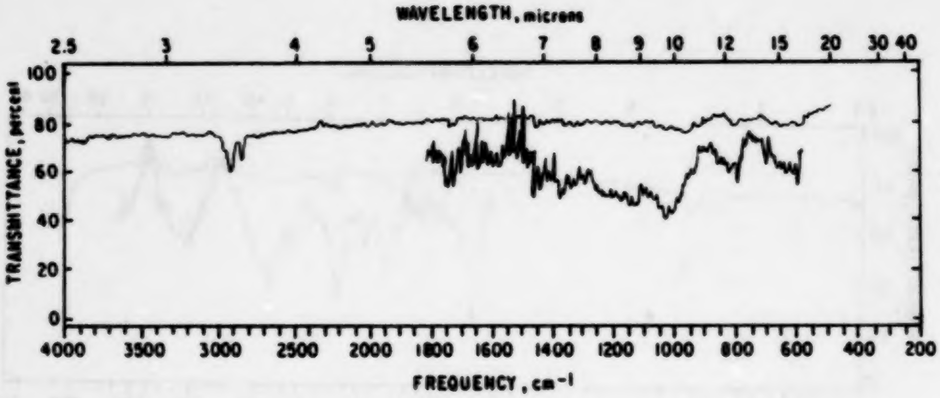

Figure D-15. IR spectrum of XAD-2 resin from SASS-2, LC fraction 1. Peaks indicate aliphatic and aromatic hydrocarbons; trace esters and ethers.

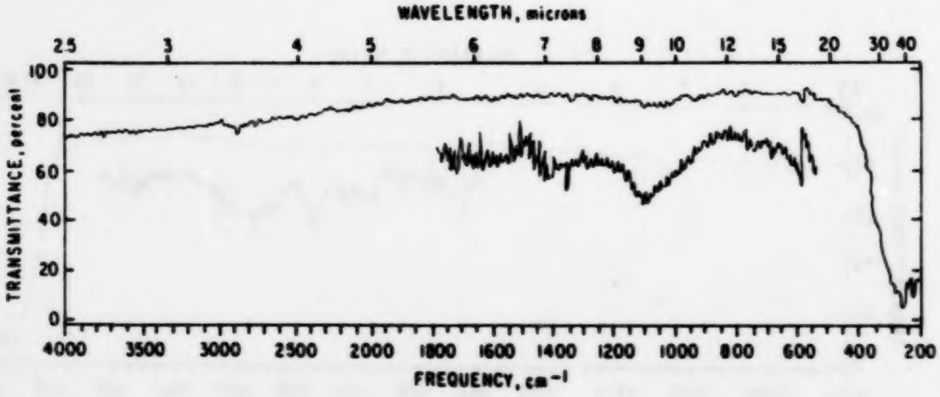

Figure D-16. IR spectrum of XAD-2 resin from SASS-2, LC fraction 2. Peaks indicate hydrocarbons and possible ethers.

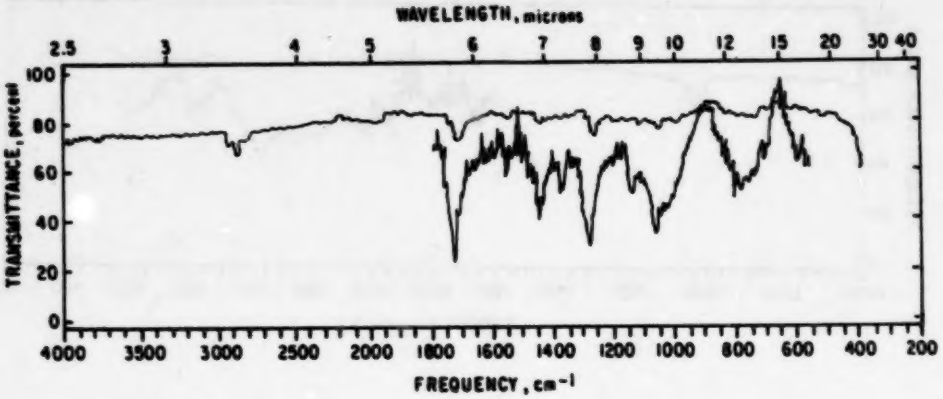

Figure D-17. IR spectrum of XAD-2 resin from SASS-2, LC fraction 3. Peaks indicate esters and trace saturated hydrocarbons and ethers.

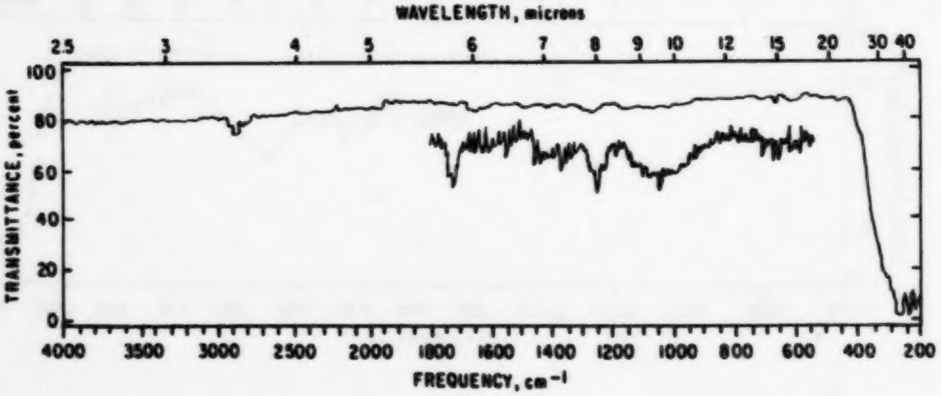

Figure D-18. IR spectrum of XAD-2 resin from SASS-2, LC fraction 4. Content of spectrum is less than or equal to that of blank.

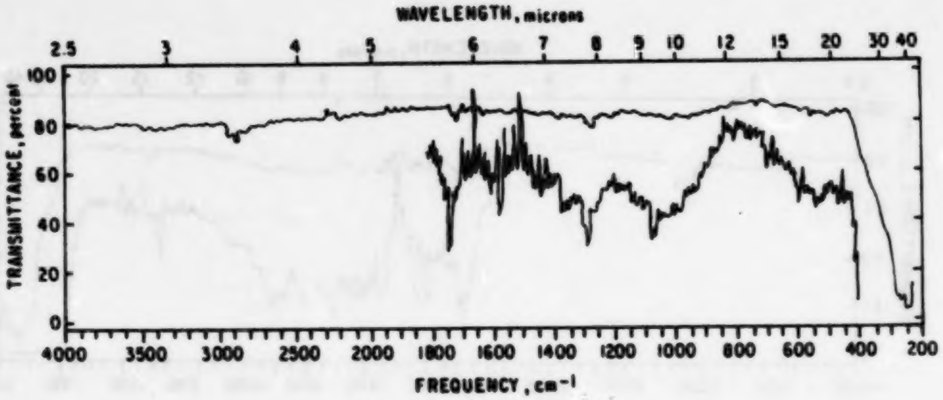

Figure D-19. IR spectrum of XAD-2 resin from SASS-2, LC fraction 5. Content of spectrum is less than or equal to that of blank.

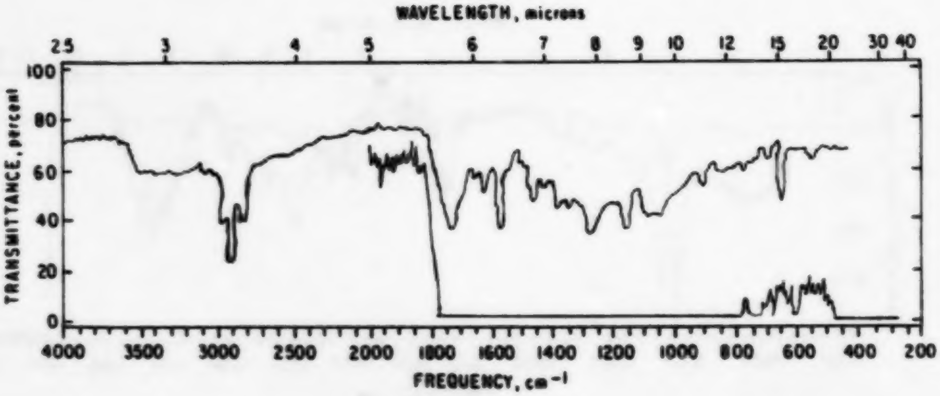

Figure D-20. IR spectrum of XAD-2 resin from SASS-2, LC fraction 6. Major peaks indicate esters, ketones; possible amines, alcohols, phenols, ethers and nitrocompounds.

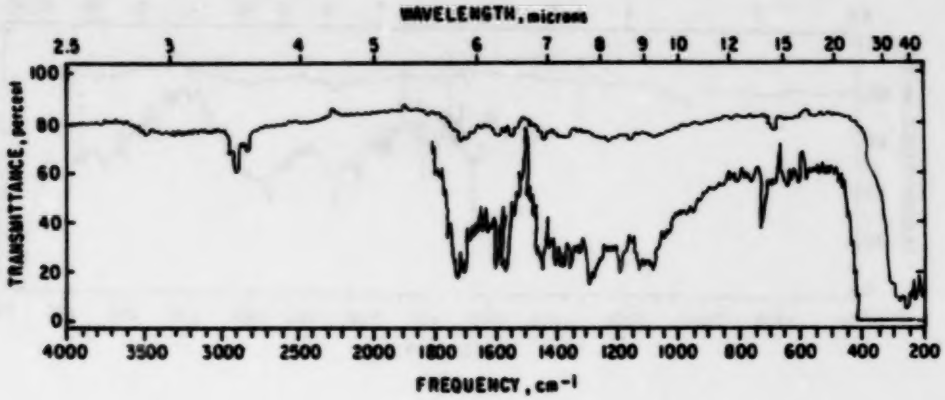

Figure D-21. IR spectrum of XAD-2 resin from SASS-2, LC fraction 7. Major peaks indicate unsaturated esters, saturated and unsaturated ketones; possible ethers and nitrocompounds.

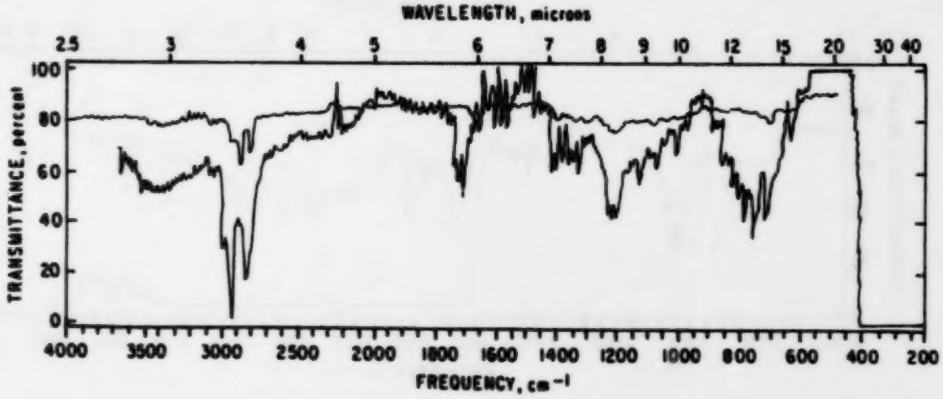

Figure D-22. IR spectrum of module rinse from SASS-2. Major peaks indicate aliphatic and aromatic hydrocarbons; saturated, unsaturated and aryl esters; possible ethers and saturated ketones.

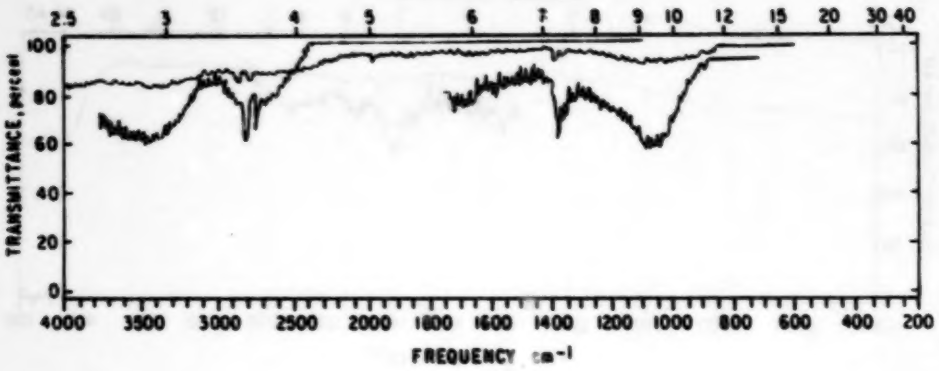

Figure D-23. IR spectrum of module rinse from SASS-2, LC fraction 1. Content of spectrum is less than or equal to that of blank.

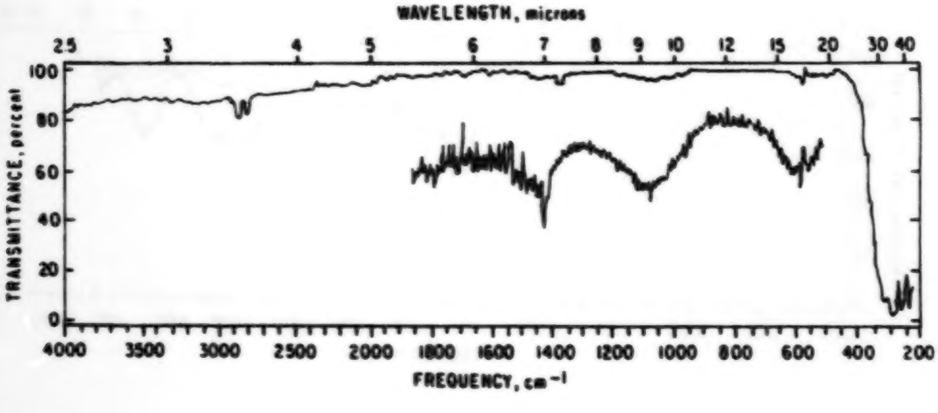

Figure D-24. IR spectrum of module rinse from SASS-2, LC fraction 2. Spectrum indicates aliphatic hydrocarbons.

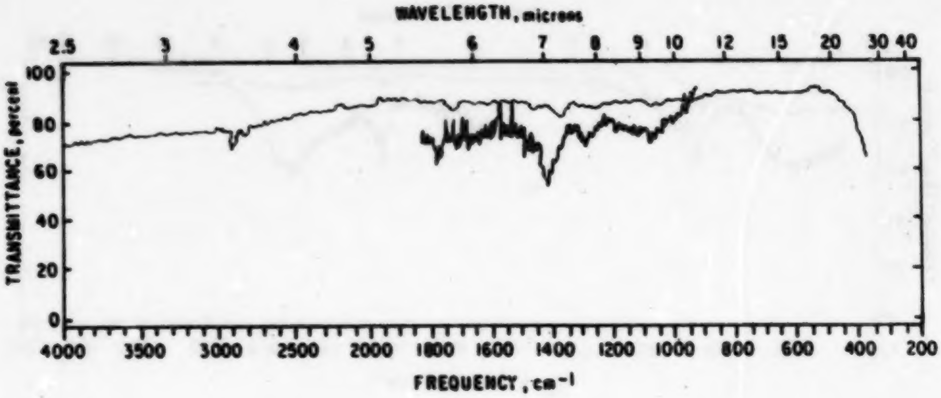

Figure D-25. IR spectrum of module rinse from SASS-2, LC fraction 3. Content of spectrum is less than or equal to that of blank.

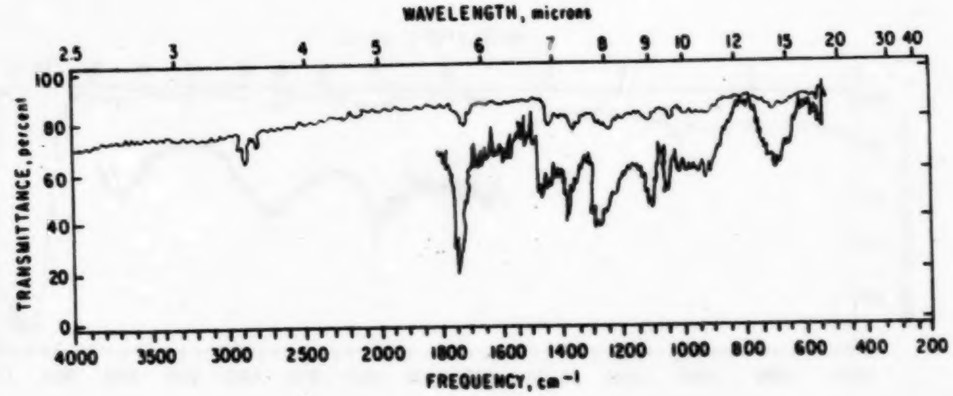

Figure D-26. IR spectrum of module rinse from SASS-2, LC fraction 4. Major peaks indicate saturated, unsaturated and aryl esters; possible ethers.

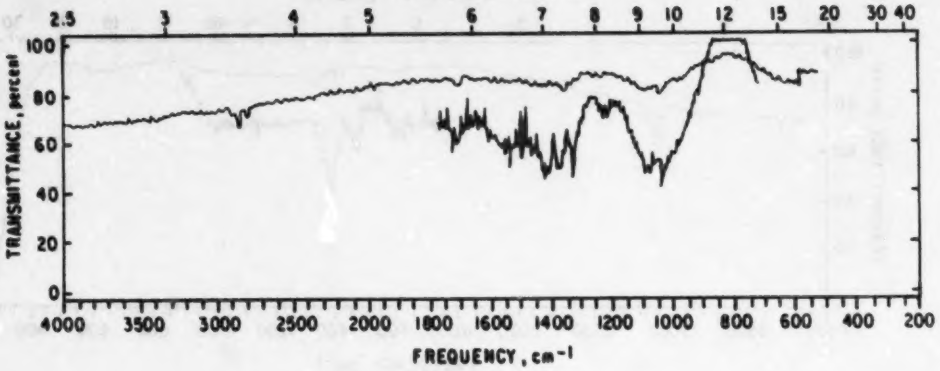

Figure D-27. IR spectrum of module rinse from SASS-2, LC fraction 5. Peaks indicate saturated, unsaturated and aryl esters.

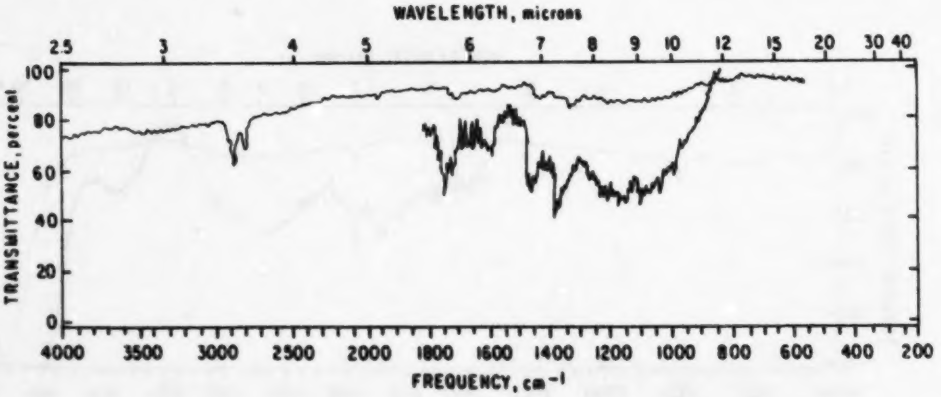

Figure D-28. IR spectrum of module rinse from SASS-2, LC fraction 6. Peaks indicate saturated, unsaturated and aryl esters.

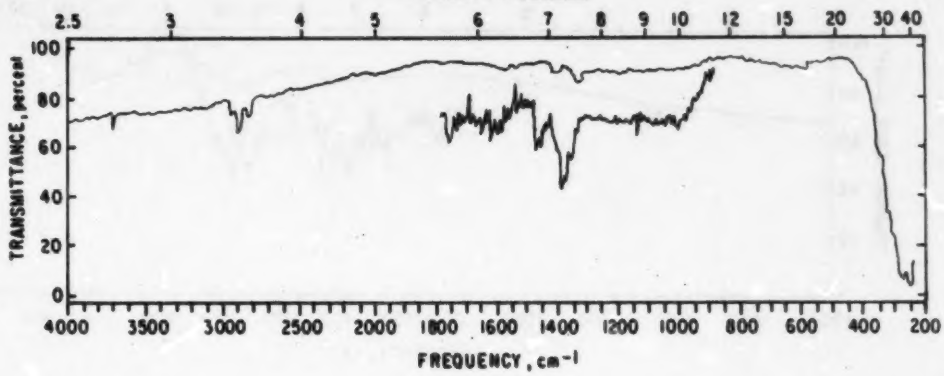

Figure D-29. IR spectrum of module rinse from SASS-2, LC fraction 7. Spectrum indicates saturated ethers.

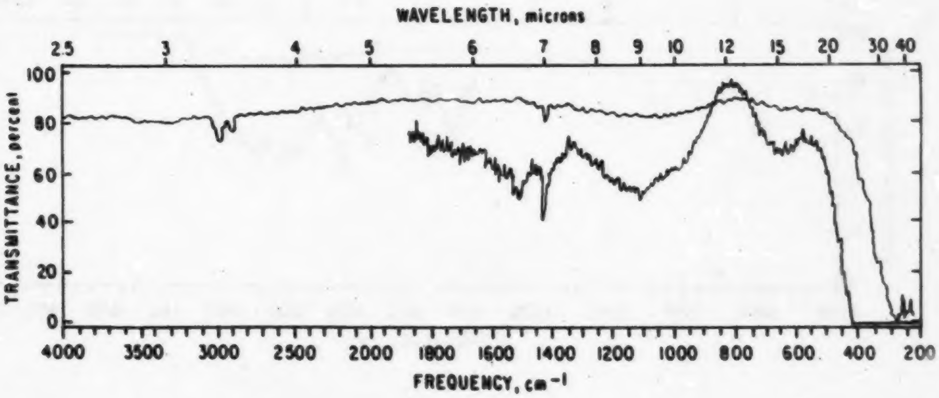

Figure D-30. IR spectrum of condensate extract from SASS-2. Peaks indicate trace aliphatic ethers.

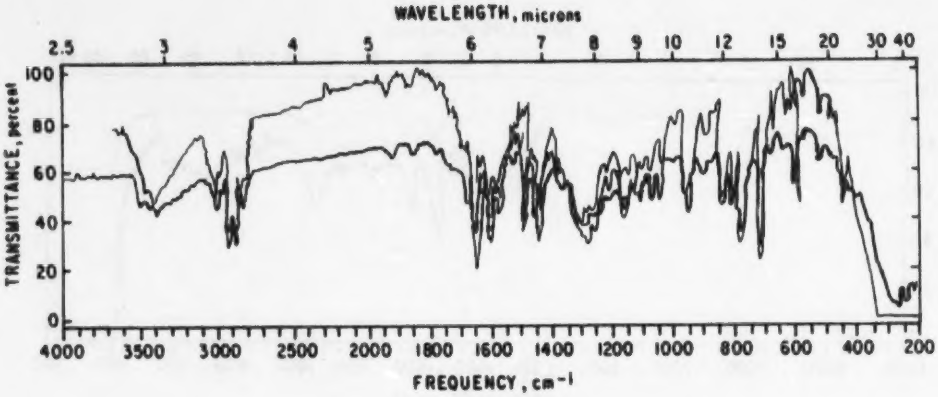

Figure D-31. IR spectrum of Tenax resin from RAC-2. Major peaks indicate primary and secondary amides, ethers, hydrocarbons; possible amines, alcohols and phenols.

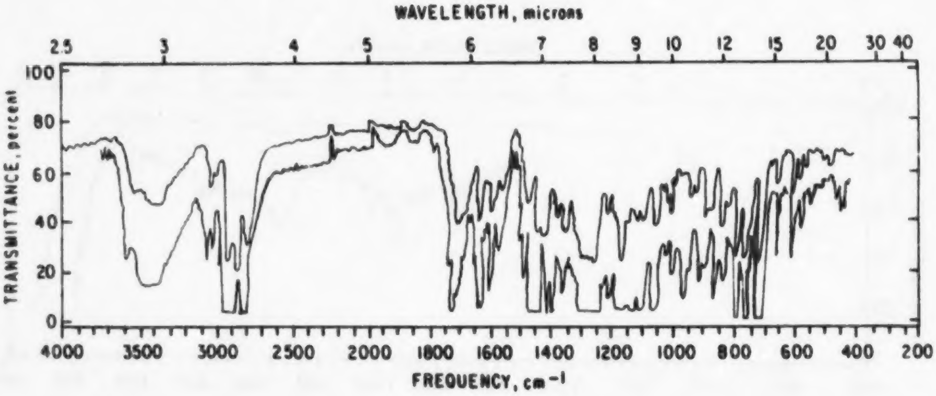

Figure D-32. IR spectrum of Tenax resin from RAC-4. Major peaks indicate hydrocarbons, esters, ketones; possible phenols and alcohols, amines, amides and ethers.

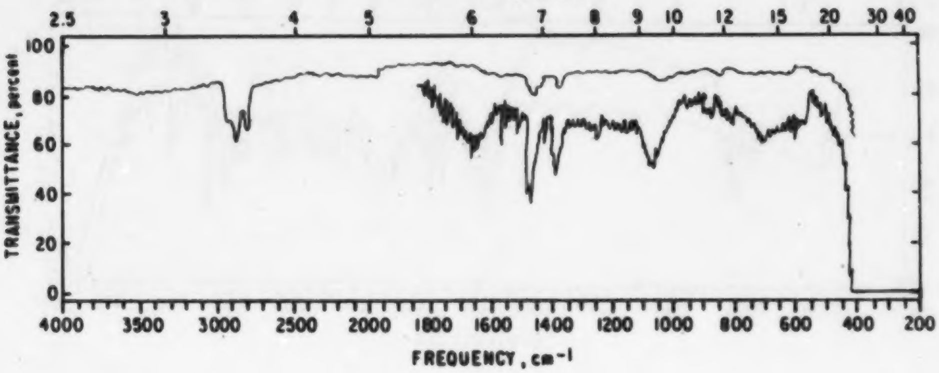

Figure D-33. IR spectrum of Tenax resin from RAC-4, LC fraction 1. Spectrum indicates saturated and aromatic hydrocarbons.

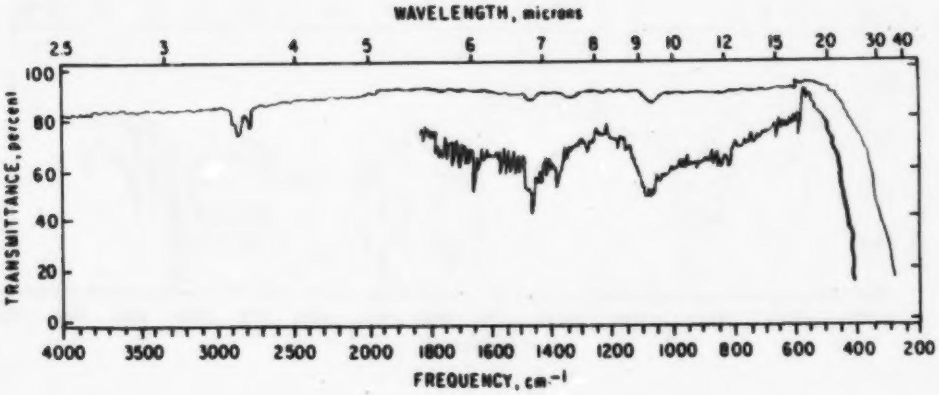

Figure D-34. IR spectrum of Tenax resin from RAC-4, LC fraction 2. Peaks indicate saturated and unsaturated hydrocarbons.

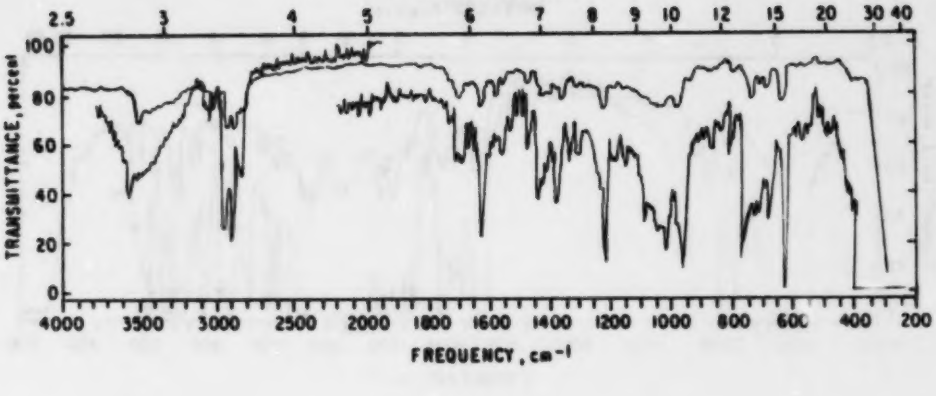

Figure D-35. IR spectrum of Tenax resin from RAC-4, LC fraction 3. Major peaks indicate substituted aromatics, esters; possible amines, amides, ethers and unsaturated alcohols.

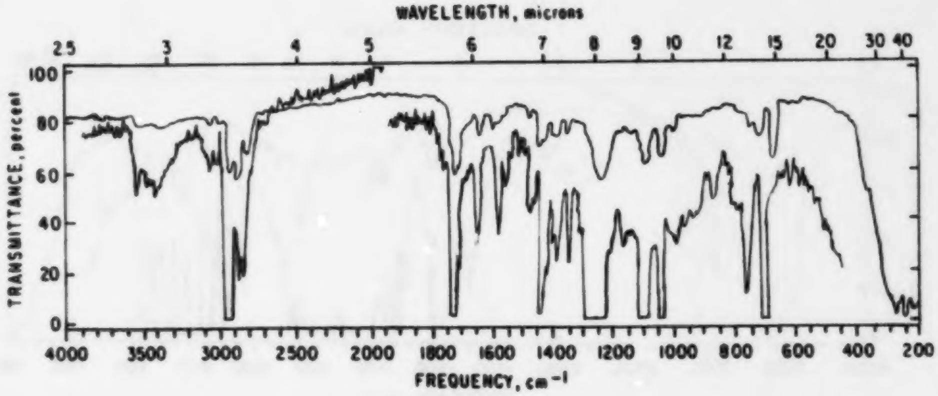

Figure D-36. IR spectrum of Tenax resin from RAC-4, LC fraction 4. Peaks indicate esters, ethers, amines and amides; possible unsaturated alcohols and nitrosubstituted compounds.

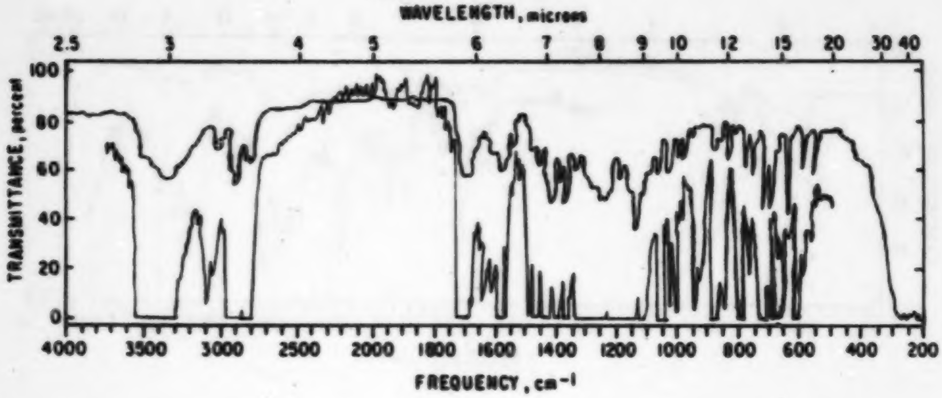

Figure D-37. IR spectrum of Tenax resin from RAC-4, LC fraction 5. Spectrum indicates esters, ketones; possible amides, amines, ethers, alcohols and phenols.

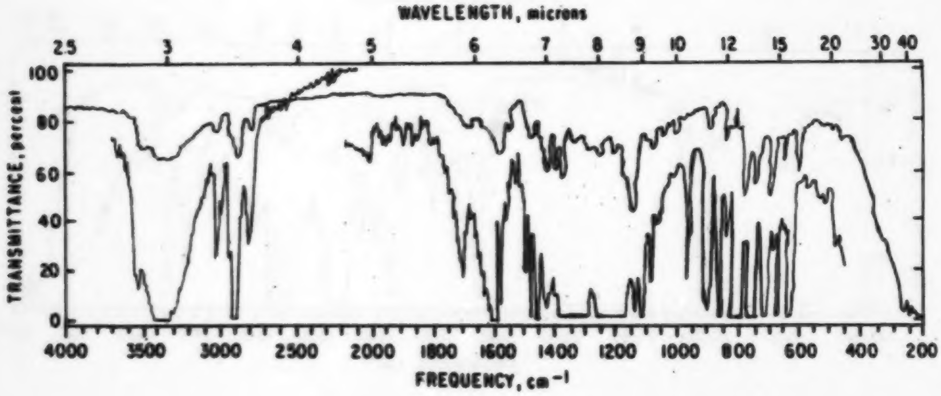

Figure D-38. IR spectrum of Tenax resin from RAC-4, LC fraction 6. Peaks indicate esters and ketones; possible amides, amines, ethers, alcohols and phenols.

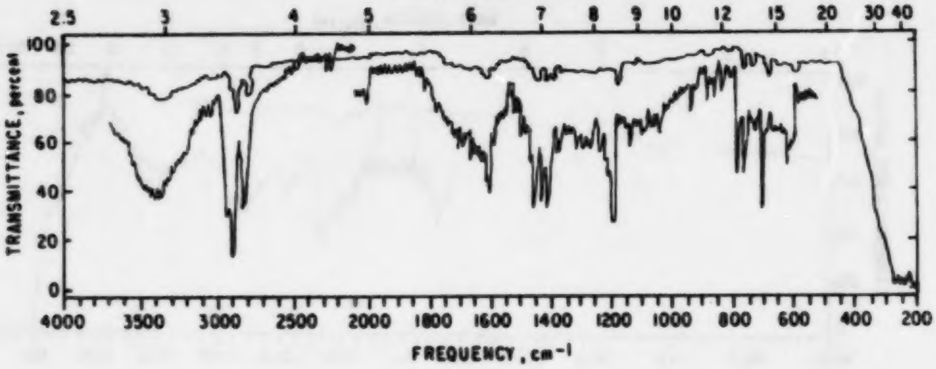

Figure D-39. IR spectrum of Tenax resin from RAC-4, LC fraction 7. Spectrum indicates ketones and esters; possible ethers, phenols, amines and amides.

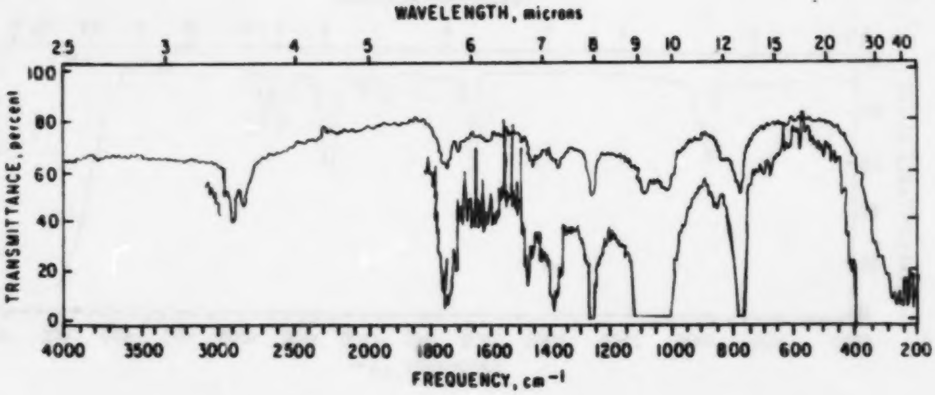

Figure D-40. IR spectrum of RAC 1-5 particulate sample. Major peaks indicate esters, ketones, saturated hydrocarbons; possible ethers, substituted aromatics and organosilicon compounds.

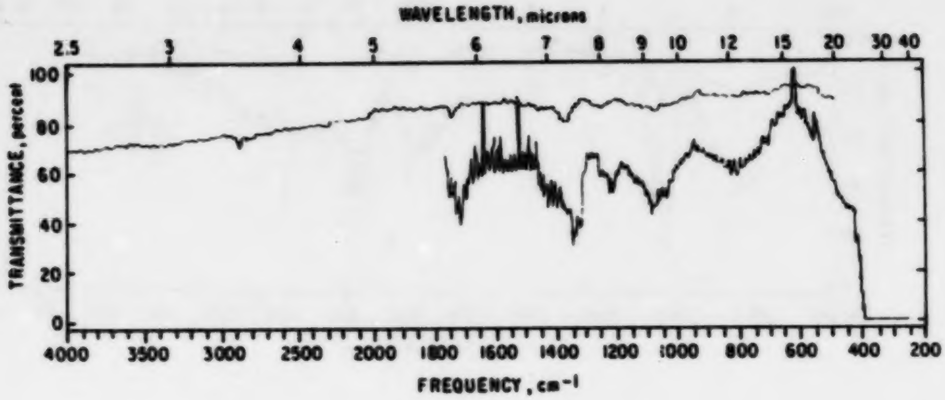

Figure D-41. IR spectrum of regenerator bed sample. Spectrum indicates aryl and unsaturated esters and ethers.

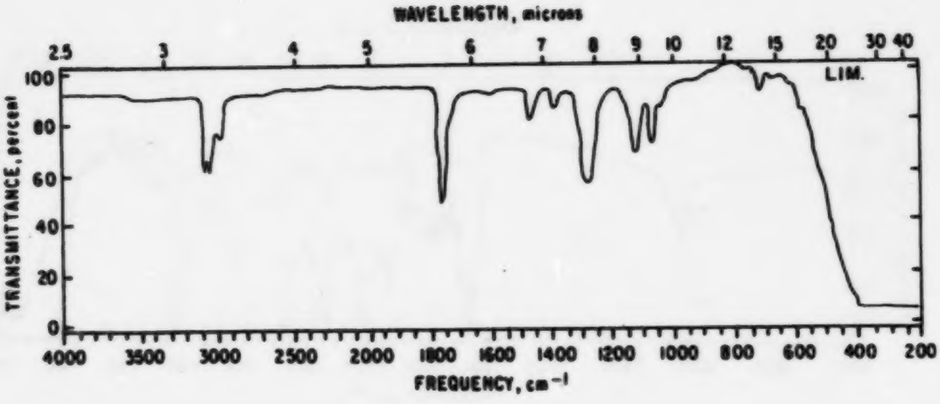

Figure D-42. IR spectrum of limestone, total methylene chloride extract. Functional groups present include methyl and methylene, carbonyl, and aromatic esters.

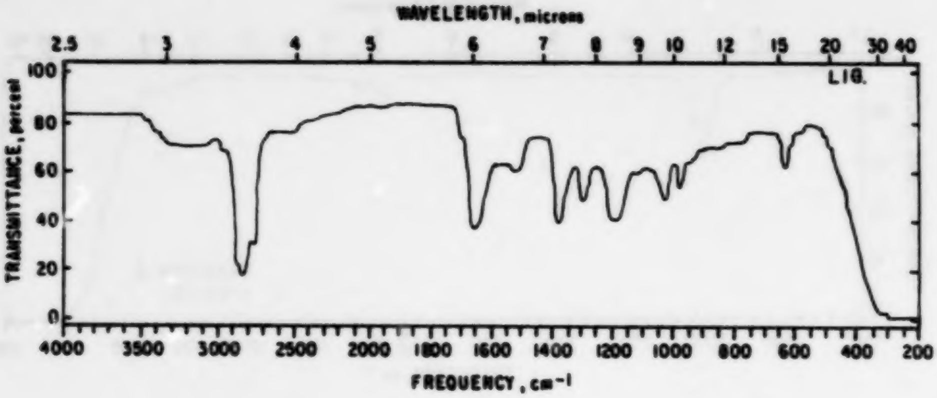

Figure D-43. IR spectrum of lignite, total methylene chloride extract. Spectrum indicates presence of alcohols and/or amines, methyl and methylene groups, carbonyls and aromatics.

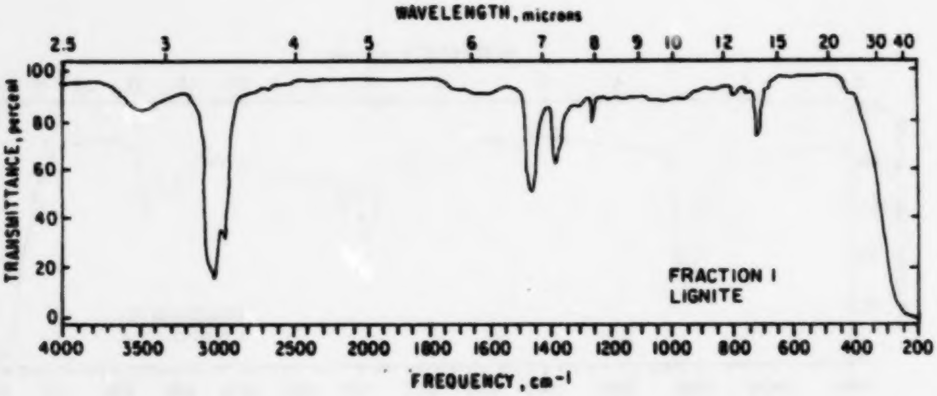

Figure D-44. IR spectrum of lignite, LC fraction 1. Groups found are aliphatics and possibly phenols.

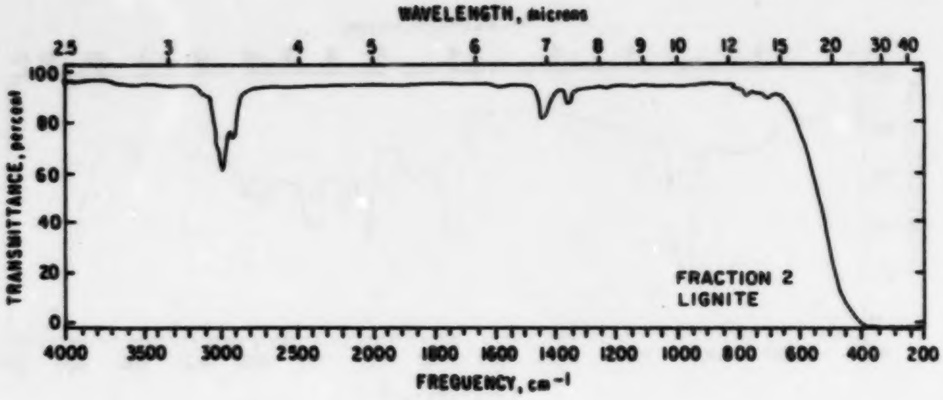

Figure D-45. IR spectrum of lignite, LC fraction 2. Presence of polycyclic organic hydrocarbon is indicated.

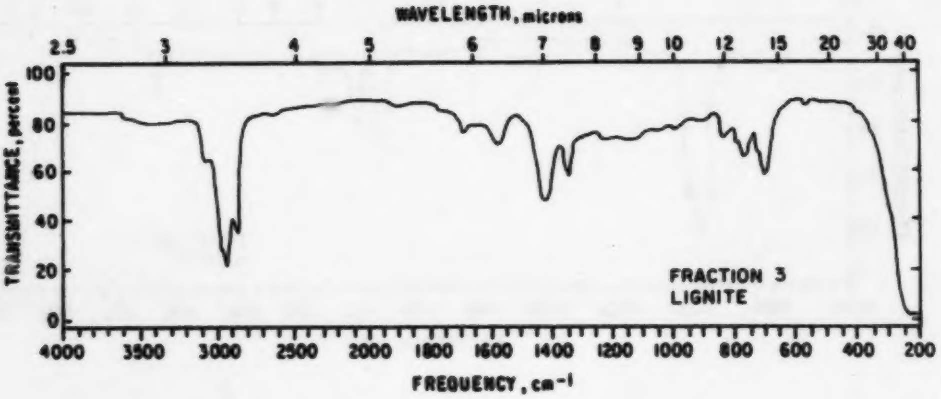

Figure D-46. IR spectrum of lignite, LC fraction 3. Spectrum indicates that halo substituted aromatics, amines and carbonyl functional groups are present.

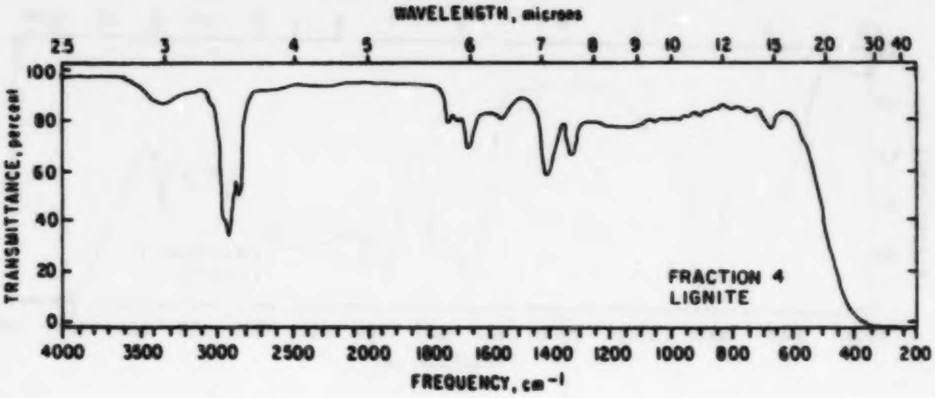

Figure D-47. IR spectrum of lignite, LC fraction 4. Presence of carbonyls detected.

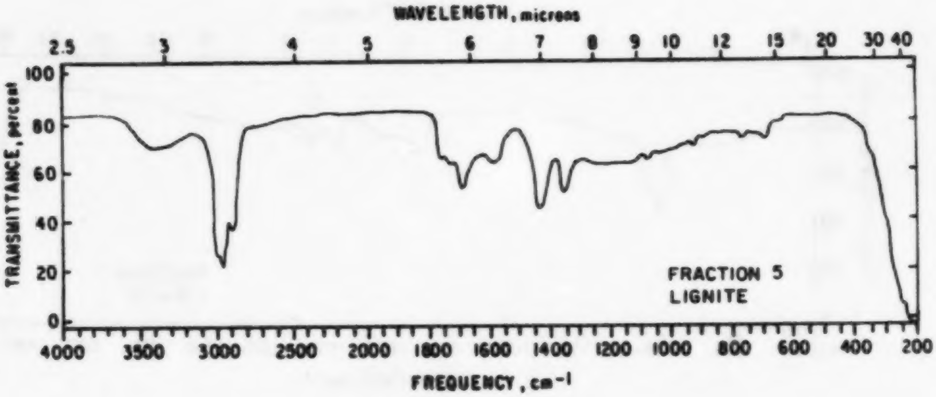

Figure D-48. IR spectrum of lignite, LC fraction 5. Presence of carbonyls detected.

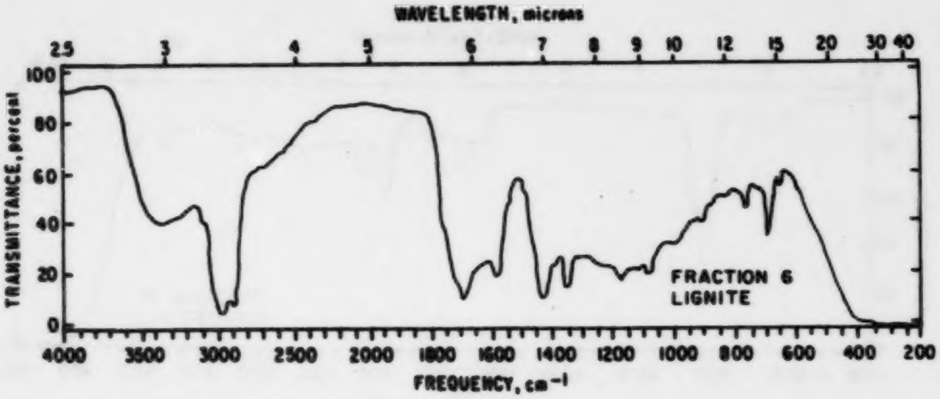

Figure D-49. IR spectrum of lignite, LC fraction 6. Aliphatic amines and possibly phenols present.

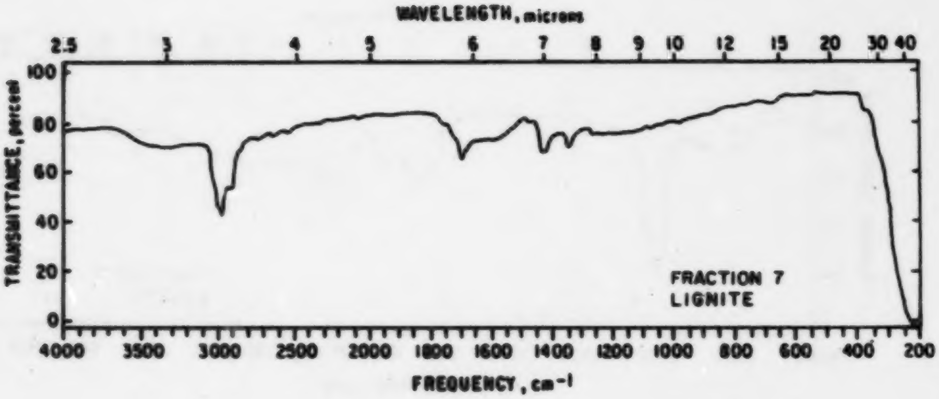

Figure D-50. IR spectrum of lignite, LC fraction 7. Carbonyls are indicated.